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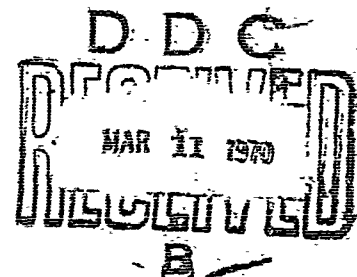
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# A SECOND-ORDER NUMERICAL METHOD OF CHARACTERISTICS FOR THREE-DIMENSIONAL SUPERSONIC FLOW

## VOLUME II. COMPUTER PROGRAM MANUAL

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A SECOND-ORDER NUMERICAL METHOD OF CHARACTERISTICS  
FOR THREE-DIMENSIONAL SUPERSONIC FLOW  
VOLUME II. COMPUTER PROGRAM USER'S MANUAL

V. H. Ransom, M. C. Cline, J. D. Hoffman and H. D. Thompson

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## Foreword

The present study is part of the program "An Analytical Study of the Exhaust Expansion System (Scramjet Scientific Technology)" being conducted by the Jet Propulsion Center, Purdue University, Lafayette, Indiana, under United States Air Force Contract No. F33615-67-C-1068, BPSN 7 (63 301206 6205214). The Air Force program monitor was Lt. Gary J. Jungwirth of the Air Force Aero Propulsion Laboratory. This report presents a second-order numerical method of characteristics for three-dimensional supersonic exhaust nozzle flow analysis. Volume II is the computer program user's manual.

The contributions of Robert Craigin and Stephen Kissick in the development of portions of the computer program and the plotting routines are acknowledged.

This report was submitted by the authors on 30 November 1969.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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## ABSTRACT

A new method of characteristics numerical scheme for three-dimensional steady flow has been developed which has second-order accuracy. Heretofore all such schemes for three-dimensional flow have had accuracies less than second-order. A complete numerical algorithm for computing internal supersonic flows of the type encountered in ramjet, scramjet, or rocket propulsion systems has been developed and programmed for both the IBM 7094 and CDC 6500 computers. The method has been tested for order of accuracy using the exact solution for source flow and Prandtl-Meyer flow. The results of these tests have verified the second-order accuracy of the scheme. Additional accuracy tests using existing methods for solution of two-dimensional axisymmetric flows have shown that the scheme produces accuracies comparable to that of the two-dimensional method of characteristics. The computer program has been used to generate the flow field for several three-dimensional nozzle contours and for nonsymmetric flow into an axisymmetric nozzle. These results reveal the complex nature of three-dimensional flows and the general inadequacy of quasi-three-dimensional analyses which neglect cross-flow. An operationally convenient computer program was produced. The program has the capability to analyze nonisoenergetic and nonhomentropic flows of a calorically perfect gas or homentropic flows of a real gas in chemical equilibrium. The initial-value surface options include uniform flow, source flow, or axisymmetric tabular data. The nozzle boundary options include conical nozzles, axisymmetric contoured nozzles and super-elliptical nozzles.

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## SECTION I

### INTRODUCTION

A computer program has been developed which can be used to obtain the solution for a wide variety of internal supersonic flows having three-dimensional spatial character. The analytical method, which is the basis for the computer program, is developed in Volume I of this report. This volume (Volume II) is a description of the computer program and the results of eight sample cases. The computer program is designed primarily for use in the analysis of the flow in three-dimensional supersonic thrust nozzles; however, the program is equally applicable to three-dimensional flow within any duct which is consistent with the basic assumptions of the flow model. Specifically, the surface of the duct is assumed to be smooth (continuous first derivatives) and not to have extreme variation of the mean flow direction.

The computer program is supplied with a boundary subprogram which includes axisymmetric and super-elliptical duct shapes. For more arbitrary geometries the user must supply a replacement subprogram which describes his particular duct geometry.

The program is written entirely in Fortran IV. Two versions of the program are available: one for the IBM 7094 computer and one for the CDC 6500 computer. The overlay scheme and program listing presented in this manual are for the IBM 7094. All the sample cases have been executed on both machines, but the sample output presented in this manual is from the IBM 7094. Run times for both machines are given. The input discussion presented in this manual is valid for both versions of the program. The program can be easily modified to be compatible with other computing machines, such as the Univac 1108.

## SECTION II

### PROGRAM ORGANIZATION

#### 1. GENERAL

The program consists of a main section and thirty-six subroutines which are used to perform the five primary tasks of: 1) data input, 2) parameter initialization, 3) generation of the initial-value surface, 4) plane by plane integration to construct the solution, and 5) printout of selected results. The entire program is too large to be stored continuously in computer memory; consequently, an overlay scheme is used and the five primary tasks are performed in sequence. The overlay arrangement is presented in Figure 1. An option exists for storing the solution on tape for restart purposes. When this option is specified (see the input parameter NSTART in NAMELIST CNTRL), a file tape must be available. This tape is TAPE 7 within the program.

A wide variety of options are available to the user. The possible combinations of these options permit a wide variety of three-dimensional thrust nozzle problems to be solved.

#### 2. DATA INPUT

All required data and parameters are input by means of namelist data. Four namelists, named CNTRL, WALSBL, ARGOSBL and IVSL, are used for this purpose. The CNTRL namelist specifies parameters which control operation of the program, WALSBL specifies the nozzle wall parameters, ARGOSBL is used for specification of the thermodynamic parameters and options, and IVSL is used to input the initial-value surface data. The namelists are read from the subroutine READIN. The input data are checked for consistency and data are output to identify the particular case being run. If the input data are found to be inconsistent or conflicting, an appropriate error message is printed by subroutines ERRORS (subroutine ERRORS consists of a series of write statements for error messages which are selected by the argument, an integer, in the subroutine call statement).

#### 3. INITIALIZATION

Once the input data and parameters have been read in, initialization of the subroutines takes place. This process consists of calculating various constant values which are a function of the input parameters, and fitting of interpolation splines to tabular data where required. The three subroutines WALSUB, ARGOSUB, and INVALS must be initialized. Initialization of WALSUB and ARGOSUB is accomplished by separate subroutines called WALSB2 and ARGOSB2. The necessary parameters are transmitted to the main subroutines through named common blocks. The subroutine INVALS is initialized by calling a separate entry point, called INVAL2, of the basic subroutine.

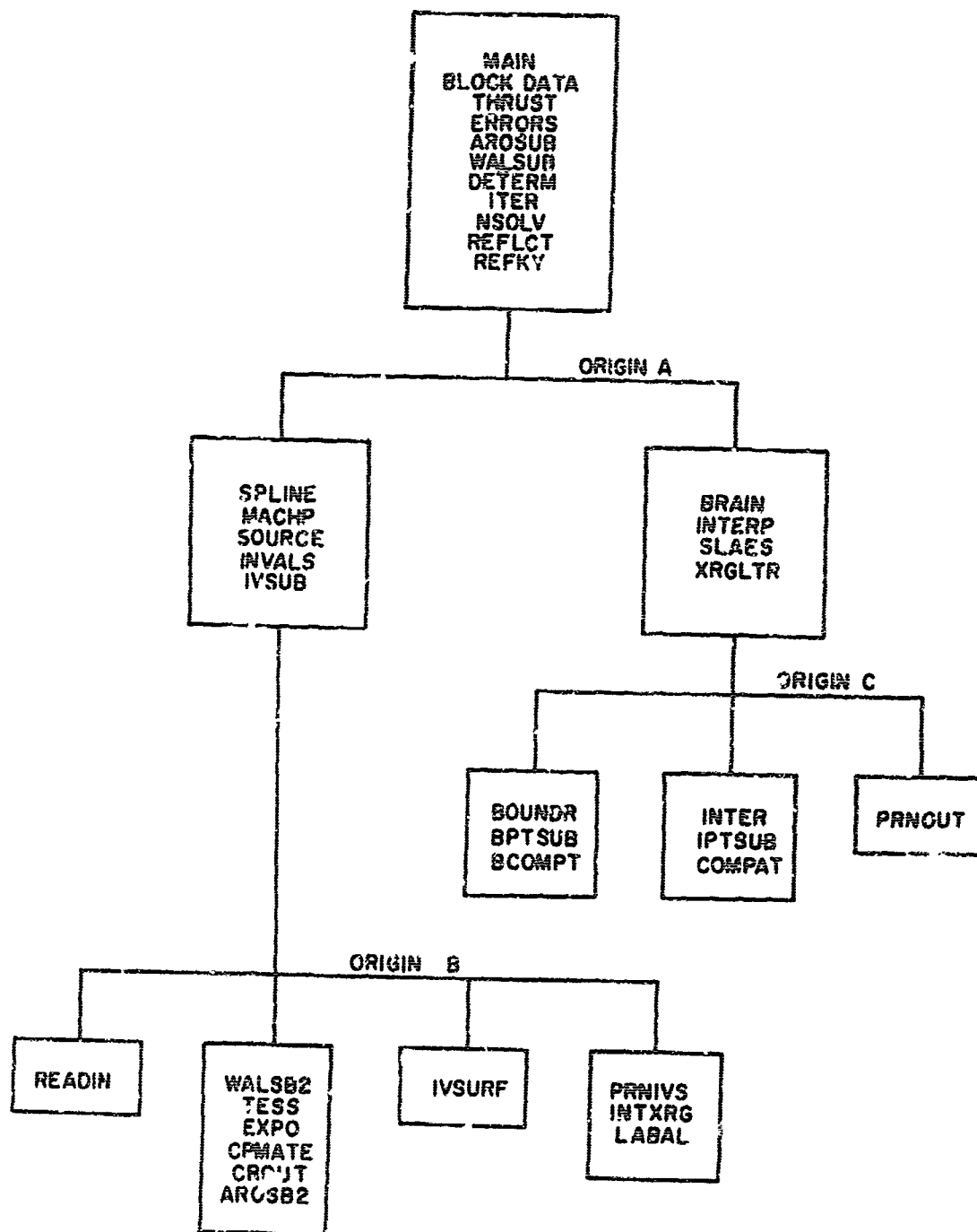


Fig. 1. Program Overlay Scheme

#### 4. INITIAL-VALUE SURFACE GENERATION

The initial-value surface point network is generated by the subroutine IVSURF, and the values of the dependent variables at each point are established by calling INVALS. The type of logical point network produced will depend upon the number of geometric planes of symmetry which are specified, and the physical location of the points of the network will depend upon the shape of the boundaries at the initial-value surface location.

Four options exist for the determination of the dependent variables on the initial-value surface. The options are: 1) a uniform homentropic flow, 2) a homentropic spherical source flow, 3) an axisymmetric nonhomentropic and nonisoenergetic flow specified by tabular input of the flow parameters as a function of the radius, and 4) generation of the dependent variables by means of a user supplied subroutine called IVSUB (the program is supplied with a sample subroutine which is a double-source model for a skewed-inlet flow).

#### 5. BOUNDARY SPECIFICATION

The solution space, and thus the initial-value surface, must be bounded by time-like surfaces. These surfaces are assumed to be stream surfaces of the flow and can consist of a smooth solid surface or a combination of a solid surface and one or two planes of symmetry. The global boundary may consist of up to eight planes of symmetry; however, it is only necessary to compute the flow in one sector. Thus, the case of a solid surface bounded by two planes of symmetry is the most general case.

The boundary surface is described by means of the subroutine WALSUB. The WALSUB subroutine that is supplied with the program has options for axisymmetric and super-elliptical boundaries. Each quadrant of the super-elliptical boundary can have different parameters so that a wide variety of completely three-dimensional shapes is possible.

If it is desired to use a boundary which cannot be described by the existing subroutine, it is necessary to replace WALSUB with a user supplied subroutine. The argument list for the subroutine calling linkage must be identical to the existing subroutine (i.e., the coordinates of a point near the boundary and the direction ratios of a line through the point, which are sufficient information to determine a line). The subroutine WALSUB determines the point of intersection of the line with the nozzle boundary. Generally two solutions exist, but the point transmitted to WALSUB is an estimate for the location of the wall point and thus the nearest intersection is the desired solution. Usually it will be necessary to obtain the solution by iterative methods.

The specification of the plane of symmetry boundaries is built into the program. The first plane of symmetry of the one or two which bound the solution space is taken to be a plane passing through the point having coordinates (XIVS, YCIVS, ZCIVS) and is parallel to the  $X_1$ - $X_2$  coordinate plane. The second plane of symmetry, where two or more planes of symmetry exist, is located such that the line of intersection with the first plane of symmetry passes through the point (XIVS, YCIVS, ZCIVS) and is parallel

to the  $X_1$  axis. In addition, the included angle between the first and second planes of symmetry is given by  $\phi = \pi/N$ , where  $N$  is the total number of geometric planes of symmetry which are common to both the nozzle and the flow.

## 6. INTEGRATION PROCESS

Once the initial-value surface has been established, the solution is generated on a series of planar surfaces which are parallel to the initial-value surface. The second-order numerical integration scheme is used to extend the solution along the network of streamlines which pass through the points on the initial-value surface. The subroutine IPTSUB is used for the interior point integration, and the subroutine BPTSUB is used for the solid boundary point integration.

The distance between successive solution surfaces is regulated such that the Courant-Friedrichs-Lewy stability criterion is satisfied at all points. The logic and calculations for the integration step size regulation are performed by the subroutine XRGLTR.

## 7. OUTPUT

The program output consists of printouts of input data and specified options for identification purposes, printing of the initial-value surface data, and subsequent printouts for each solution surface. The amount of data which is printed for the initial-data surface and each succeeding solution surface can be varied by the two parameters PRINT1 and PRINT2.

After computation of each new solution surface, the mass flow rate, thrust components and moments are calculated by numerical integration over the solution surface. In addition, flow parameters to be printed, such as Mach number, are calculated and placed in the proper units and stored for output purposes. These operations are performed by the subroutine THRUST.

The printing of data for the initial-value surface is performed by the subroutine PRNIVS, and the printing for the calculated solution surfaces is performed by the subroutine PRNOUT.

### SECTION III

#### SUBROUTINE DESCRIPTIONS

Brief descriptions of each subroutine of the program are given here to supplement the information available in the form of comments within the program.

#### 1. MAIN LINK

a. MAIN. The necessary subroutines are called for reading in data, initialization of the subroutines, generation of the initial-value surface, calculation of thrust components on the initial-value surface, printing of the initial-value surface, and initiation of the integration process.

b. BLOCK DATA. All constants are assigned values, and default values for many of the input parameters are established.

c. THRUST. The cross-sectional area, mass flow rate, thrust components and moments are established by numerical integration over the solution surface corresponding to the LL index. The initial-values and the solution values are stored in the three-dimensional arrays contained in named common SQLUTN. The first index of the arrays has dimension 2 and the initial data and solution are identified by the variable subscripts L and LL respectively. These subscripts have the range 1 to 2, and the particular values are mutually exclusive. The numerical integration is performed by dividing the cross-section into triangular elements, and a two-dimensional equivalent of the trapezoidal rule integration scheme is used. The area and centroid of each triangular element are calculated and the average mass flux, momentum fluxes and pressure are assumed to act uniformly over the element. Thus the force is considered as a pure force acting at the centroid of the element. The components of the force and the components of the moment vector are assumed to act at the origin of the coordinate system. The total thrust components are corrected by multiplying by the ratio of the mass flow rate on the initial-value surface to the calculated local mass flow rate. The calculated mass flow rate is some indication of the error in the integration scheme due to the presence of large gradients across the solution surface, and the correction procedure is based on the assumption that the specific impulse is calculated more accurately than the total force.

d. ERRORS. This subroutine consists of a collection of diagnostic messages for some of the anticipated modes of failure of the program. The error messages can be either fatal or nonfatal depending upon the type of problem. These messages are printed by calling subroutine ERRORS with an integer argument which designates the particular error. For fatal errors a program stop occurs within the subroutine, while for nonfatal errors a normal return is executed.

e. AROSUB. The speed of sound, A, the density,  $\rho$ , the square of the velocity, QS, and the three partial derivatives of the speed of sound and density are determined as functions of the independent variables

pressure P, stagnation pressure PT, and stagnation enthalpy H. The subroutine supplied with the program contains options for either a thermally and calorically perfect gas, or a real gas, which the properties are functions of the pressure only. The second option can be used only for a homentropic flow, and it permits either chemically frozen or equilibrium composition gases having real properties to be used. The subroutine has two entry points, ARQSB1 and ARQSB2, in addition to the normal entry. These entry points are used when the derivatives are not required. The first entry point is used when A, RQ and QS are desired and the second when only A, RQ, QS and T are required. The temperature, T, is used only for purposes of printout, and the name DADP in the argument list is used for transmission of this value. The subroutine ARQSB2 is used to initialize the subroutine ARQSUB. Any constant functions are evaluated, and for the option having tabular data input, the data are put in proper units and the coefficients for the cubic spline interpolation are calculated. In order to extend the capability of the program to include nonisoenergetic and nonhomentropic flows of a real gas having either frozen or equilibrium chemical composition, it will be necessary to expand or replace this subroutine. The replacement subroutine must include tabular input of the thermodynamic properties as functions of stagnation pressure and stagnation enthalpy in addition to the static pressure. The subroutine must also include provision for calculating the three partial derivatives of the speed of sound and the density. Generally three-dimensional interpolation methods are required unless some of the data can be input as analytic functions.

f. WALSUB, DETERM, ITER, and NSQLV. The subroutine WALSUB and associated subroutines, DETERM, ITER and NSQLV, are a system which is used to describe the geometry of the solid boundaries. The WALSUB system supplied with the program includes options for conical and contoured axisymmetric nozzles, and super-elliptical, three-dimensional nozzle shapes. For other nozzle shapes it is necessary to replace the WALSUB subroutine with a user supplied subroutine which has the same name and argument list (some change to subroutine READIN and named common WALSB is also required in order to include new input parameters and printout). The WALSUB subroutine is utilized in the program for locating points on the boundary. The coordinates of a point near the boundary and the direction cosines of a line through the point are transmitted to the subroutine through the argument list. The subroutine subsequently locates the nearest intersection of the line with the boundary. The coordinates of the intersection are then returned through the argument list using the same variable names as used for the input point. The direction cosines of the outer normal to the surface are also transmitted through the argument list using the same variable names as the input direction cosines. The only restrictions on the boundary are that it be continuous and have continuous first derivatives.

g. REFLCT. The logic for the reflection of points and properties at points adjacent to planes of symmetry is contained in REFLCT for ICLASS equal to 1, 2 or 3 (i.e., for 3 or more, 2 or 1 planes of symmetry, respectively). The actual reflection of points and properties is accomplished by calling one of the entry points in subroutine REFKY (i.e., REFKY, REFKZ or REFKS, for reflection about a Y-X, Z-X or on arbitrarily located plane of symmetry, respectively). The argument (K) is the first index of the point coordinates and properties stored in the arrays of named common SQLUTN.

h. REFKY. The reflection of the coordinates and properties at a specified point with respect to a designated plane of symmetry is performed in REFKY. The particular plane of symmetry is specified by calling one of the three entry points REFKY, REFKZ or REFKS. The point to be reflected is identified by its indicies which are passed to the subroutine by means of the argument list. The general principles of reflection which are used in these subroutines are as follows: 1) the image point is located such that the plane of symmetry is the perpendicular bisector of the line joining the point and the image point, 2) scalar properties are unchanged by reflection, and 3) vector properties are reflected such that the magnitude and the component parallel to the plane of symmetry are unchanged while the component perpendicular to the plane of symmetry is reflected with opposite sense. The analytical development of the reflection process is presented in Volume I.

## 2. LINK A1

a. SPLINE. This subroutine fits a cubic interpolation spline to an array of tabular data. A cubic polynomial is fit between each consecutive pair of points such that the slopes of the adjoining cubic polynomials are matched at the data points. The slopes at the two end points of the array of data must be specified. The parameters of the argument list are: KNOT, number of data points in the table; XK(I), the value of the independent variable at the Ith data point; VALUE(I,1) the value of the dependent variable at the Ith data point; VALUE(I,2), the slope at the first and last data points (i.e.,  $I = 1$  and  $I = \text{KNOT}$ ); and COEF(3,I), the four coefficients of the cubic polynomial between the Ith and (I+1)th points.

b. MACHP. This subroutine uses the ARQSB1 subroutine to obtain the pressure,  $P$ , and velocity magnitude,  $Q$ , which correspond to a specified Mach number,  $M$ , stagnation pressure,  $PT$ , and stagnation enthalpy,  $H$ . A Newton-Raphson iteration scheme is used to obtain convergence after an initial estimate of the pressure is calculated using ideal gas relations with an assumed specific heat ratio equal to 1.2. The iteration is continued until two successive values of the pressure agree to within 0.0000001, or a maximum of 50 iterations are completed. In the latter case a fatal error message is generated.

c. SOURCE. The pressure and velocity magnitude of a spherical source flow are calculated by a Newton-Raphson iterative scheme using the ARQSB1 subroutine to determine the thermodynamic properties. The mass flux at any point in a spherical source flow can be determined from geometric and mass conservation principles if the mass flux is known at one point distinct from the source point. Thus, the mass flux is used as the independent variable for determining the individual properties such as pressure, density and velocity magnitude. In the argument list, PSV is the mass flux, H1 the stagnation enthalpy, PT1 the stagnation pressure, PRESS the pressure, and Q the velocity magnitude. The iterative process continues until two successive pressures agree to within less than  $1.0 \times 10^{-7}$  percent, or a maximum of 50 iterations is exceeded. In the latter case a fatal error message is generated. An initial approximation of the pressure, PSOURC, is required and is stored in named common /ARQ1/. After the subroutine has been called once, this initial guess will be taken as the previously obtained answer.

d. INVALS. The dependent variables  $u$ ,  $v$ ,  $w$ ,  $p$ ,  $P$  and  $H$  are calculated at a designated point of the initial-value surface. The particular point is identified by the indices transmitted in the argument list, (1,J). Four flow models may be selected by specification of a value for IVSTYP ranging from 1 to 4. The four options include: for IVSTYP = 1, a uniform flow having a specified Mach number and flow direction; for IVSTYP = 2, a spherical, homentropic source flow; for IVSTYP = 3, an axisymmetric, non-homentropic, and nonisoenergetic flow which is specified by tabular input of Mach number, flow direction, stagnation pressure and stagnation enthalpy as functions of the radius; and for IVSTYP = 4, a user supplied subroutine which can be used to provide any desired flow model. The indices in the argument list permit the subroutine to locate the Y and Z coordinates of the point at which the dependent variables (the velocity components, the pressure, the stagnation pressure and the stagnation enthalpy) are to be calculated. The subroutine subsequently evaluates the dependent variables as functions of the spatial coordinates X, Y and Z. The subroutine must be initialized by calling the second entry point INVAL2 which does not have an argument list.

e. IVSUB. This subroutine is normally supplied by the user, thus allowing any flow model desired to be programmed for generation of the initial-value surface data. A sample subprogram is supplied with the program to serve as an example. It consists of the super-position of two spherical sources as an approximation to a skewed flow. The subroutine is initialized by calling the second entry point, IVSB2 (this is done by INVALS).

### 3. LINK A2

a. BRAIN. The marching type integration between parallel planar surfaces is regulated by this subroutine. The integration  $\Delta\eta$  loop ranges are calculated as functions of the number of planes of symmetry, and if a start from tape has been specified, the initial-value surface data are read from tape, the thrust data are calculated, and the initial-value surface data are printed. The subroutine subsequently calculates the net points over the boundaries and the interior of the flow and prints out the solution for each successive solution surface. A check is made on the X1 coordinate of each new surface to see if the specified integration distance, XMAX, has been exceeded, and if so, the X1 coordinate of the last solution surface is adjusted to coincide with XMAX.

b. INTERP. The second-order bivariate interpolating polynomials are fit by the method of least squares to a group of nine neighboring points in this subroutine. The nine points are selected by manipulation of the indices of the storage arrays for the six dependent variables, the velocity components  $u$ ,  $v$ ,  $w$ , the pressure,  $p$ , the stagnation pressure,  $P$ , and the stagnation enthalpy,  $H$ . The indices of the points are determined relative to the indices of the base point in the initial-value surface using stencils of index increments stored in the data arrays IK and JK. Nine different stencils are available and the particular one to be used at a given point is determined from the leading digit of the integer label KCLASS, which is assigned initially by the subroutine LABEL. A system of six simultaneous, linear, algebraic, least squares equations are solved for the polynomial coefficients using the subroutine SLAES.

c. SLAES. This subroutine is an adaption of the IBM library subroutine GELS for the solution of systems of symmetric linear algebraic equations. The subroutine is used only by subroutine INTERP to solve the sixth-order least squares system of equations, and thus has fixed dimensions for the coefficient arrays A and R. The 21 coefficients of the upper half of the symmetric coefficient matrix are stored columnwise in the array A, and the polynomial coefficients of the polynomials are stored columnwise in the array R (named B in all other subroutines and contained in labeled common INTRP).

d. XRGLTR. The main entry of this subroutine is called after each point calculation for the purpose of calculating the permitted step size and searching for the most restrictive point on the solution surface. The entry point XRGLT1 is called after the entire solution surface has been generated for the purpose of predicting the step size to be used for the next solution surface. The prediction of the new step size is based on the permitted step size for the present and previous solution surfaces at the most restriction point of the present surface. A safety factor, SAFTY, is used as a multiplier for the predicted step size and reflects past experience with respect to whether previous predicted step sizes were too optimistic or too conservative.

#### 4. LINK B1

READIN. All input data and parameters are read from cards by this subroutine. It is the first subroutine called by the main program. Variable printed outputs are generated which depend upon the type of problem which is specified by the input data. With the exception of the title, which is input on the first data card, all data input is by means of the four namelists, CNTRL, WALSBL, ARGSBL, and IVSL. Some of the input parameters are checked for consistency and if any conflicts are found, appropriate error messages are generated. The nozzle contour data are checked to see if any of the coordinate plane intercepts are conical (i.e., straight lines). The intercept is assumed to be conical if the slopes at the tangent point and at the exit are equal. The nozzle exit radius is then calculated to correspond to the wall slope and the nozzle length, thus eliminating the possibility of conflicting input data.

#### 5. LINK B2

a. WALSB2, CPMATE, TESS, EXP0 and CRQUT. These subroutines are used for initialization of the WALSUB group of subroutines which are used to define the nozzle boundary. The subroutine WALSB2 contains the logic for generating the possible wall contour variations and calls the other subroutines as appropriate. CPMATE is used for calculation of the coefficients for the equations, circles and general parabolas, which are used to define the nozzle-coordinate plane intercept contours. TESS is used to test to see if the intercept parameters are all equal in each quadrant. EXP0 is used to calculate the coefficients for the quadratic equations which are used to specify the variation of the super-elliptical exponents as a function of nozzle length. CRQUT is a library subroutine for the solution of systems of linear, simultaneous algebraic equations and is called only from subroutine CPMATE.

b. APR@SB2. This subroutine is used for initialization of the APR@SUB subroutine. If a thermally and calorically perfect gas is specified, then only five functions of the specific heat ratio, GAMMA, are calculated. If the gas properties are specified by means of tabular input, then the data are put in the proper units and checked for monotonic variation of the independent variable, Mach number, M. Subroutine SPLINE is used to fit cubic splines to the data points.

#### 6. LINK B3

IVSURF. The network of points on the initial-value surface are generated, and the coordinates are stored in the Y and Z arrays. These points define the streamlines which are subsequently extended to each new solution surface. The network is varied depending upon the number of planes of symmetry and the characteristic dimension of the surface arrays, NP. The outermost points of the system of points are located on the flow boundary by the use of WALSUB. After the coordinates of each point have been calculated, the subroutine INVALS is called for the purpose of calculating the values of the dependent variables on the initial-value surface. If planes of symmetry exist, the reflection of all properties is effected by calling REFLECT and by reflecting directly the properties PT and H. The reflection of PT and H is done separately from the reflection of the properties velocity and pressure, because this operation is required only once on the initial-value surface, whereas the other properties must be reflected at each new solution surface.

#### 7. LINK B4

a. PRNIVS. This subroutine produces a printout of the initial-value surface data and the thrust parameters. Three options are available: 1) print thrust data, boundary point data, and interior point data; 2) print thrust parameters and boundary point data only; and 3) print thrust parameters only.

b. INTXRG. Initial data for the X1 step size regulation are generated. The subroutine sweeps over the array of points and generates the relative step size parameter, DXDL, and the distance to the nearest point, RM, at each point on the initial-value surface. At the same time a search is made for the most restrictive point. After completion of the sweep, the permitted integration step size is calculated at the most restrictive point.

c. LABAL. Labels are generated for each point in the initial-value surface arrays which are used to determine the type of stencil (see Volume I, Appendix G) to be used for selection of neighboring points for interpolation. The label consists of a two digit integer which is stored in the array KLASS. The first digit is used to denote the one-eighth sector of the array (numbering is counterclock wise from the Y axis) in which the point is located, and the second digit designates one of nine stencils for use in interpolation. The stencil variation is required to account for different boundary points arrangements, and to obtain the nearest neighbors of each point in the array. The label is used by subroutine INTERP to select one of the nine stencils stored as data and, through index manipulation, to generate the indicial coordinates for the system of points to be used for interpolation. In generation of the indicial coordinates, the particular one-eighth sector of the grid, designated by the first digit of the label, is considered.

## 8. LINK C1

a. BBOUNDR. This subroutine contains the logic for integration over the boundary points of the flow. It is a subdivision of the overall logic subroutine BRAIN which was written separately in order to permit overlaying the subroutines for boundary point and interior point calculation.

b. BPTSUB. In this subroutine, the location and properties of a new boundary point of the flow are calculated by the second-order method of characteristics technique developed in Vol. 1. The argument list consists of the coordinates and the stagnation pressure and stagnation enthalpy of the streamline along which the solution is to be extended, and the coordinates, dependent variables, and relative step size parameter at the new solution surface. The interpolating polynomials are generated by subroutine INTERP. These equations are used to generate values for the dependent variables at the points in the initial-value surface which are used in the integration process, including the streamline intersection at which the values are known (the interpolated values are used at the streamline intersection for stability reasons). The position of the solution point is approximated and WALSUB is called to establish the point on the boundary and to calculate the components of the unit outer normal to the boundary. The reference vector system,  $u_i/q$ ,  $\alpha_i$ , and  $\beta_i$ , is established at the new point such that  $\beta_i$  coincides with the outer normal. Next the network of three bicharacteristics and the streamline is constructed, and the dependent variables are determined at the intersections of the bicharacteristics and the streamline with the initial-value surface using the interpolating polynomials. The reference vector set  $u_i/q$ ,  $\alpha_i$ , and  $\beta_i$  are next established at each of the network intersections with the initial-value surface. Finally the new values for the dependent variables at the solution point are obtained by simultaneous solution of the compatibility equations using the subroutine BCQMPT. A convergence test is made to see if the values of pressure on two successive iterations agree fractionally to within 0.0001. When convergence is obtained, the step size regulating parameter DXDL is evaluated.

c. BCQMPT. This subroutine is a subdivision of BPTSUB and performs the solution of the compatibility equations for the new values of the dependent variables at a boundary point. All parameters and the solution are transmitted to BPTSUB through the labeled common block /PTSUB/. Cramer's rule is used for solution of a system of four equations for the four unknown velocity components  $u_i$  and the pressure  $p$ .

## 9. LINK C2

a. INTER. This subroutine contains the logic for integration over the interior point of the flow and is also a subdivision of BRAIN to permit overlaying the interior and boundary point integration subroutines.

b. IPTSUB. This is the basic integration subroutine for interior points and is essentially the same as BPTSUB. The differences are that four bicharacteristics are used instead of three and the reference vector set  $u_i/q$ ,  $\alpha_i$ , and  $\beta_i$  are oriented with respect to the pressure gradient rather than the boundary outer normal as in BPTSUB. In this case the vectors  $\alpha_i$  and  $\beta_i$  are chosen such that they straddle the plane formed by the two

vectors  $u_i$  and  $\nabla p$ . A separate subroutine, COMPAT, is used for solution of the compatibility equations, which in this case includes the fourth bicharacteristic compatibility equation rather than the boundary tangency condition. All other operations are the same as in BPTSUB.

c. COMPAT. This subroutine is a subdivision of IPTSUB which includes the solution of the compatibility equations for the values of the dependent variables at the solution point. The subroutine is essentially the same as BCMPPT except that the fourth bicharacteristic compatibility equation is used instead of the boundary tangency condition.

#### 10. LINK C3

PRNSUT. This subroutine is used for printing the properties at each new solution surface and is essentially the same as PRNIVS. The differences are only in the headings which are printed. A separate subroutine was utilized because of convenience in generating the overlay structure.

## SECTION IV

### INPUT PARAMETERS

#### 1. INTRODUCTION

The various options which are available in the program are specified by certain input parameters and data which are entered through the four NAMELISTS CNTRL, WALSBL, ARQSBL, and IVSL. Only those parameters and data which are pertinent for a particular option need to be input. Many parameters have default values which are set by the block data subprogram and may not need to be specified for this reason. The parameters of each namelist are described in the following discussion, and where appropriate, both default and typical values are given.

#### 2. TITLE CARD

The first card of each data deck is a title card consisting of 72 alphanumeric characters of identifying information. This card may be blank, or contain any combination of allowable FORTRAN characters. This card must always be the first card of the data deck, even if no information is specified on the card. The format of the card is (12A6).

#### 3. NAMELIST CNTRL

IVSTYP An integer parameter used to select one of four initial-value surface options as follows:

<u>value</u>	<u>initial-value surface option</u>
1	uniform, parallel flow
2	homotropic, spherical source flow
3	axisymmetric, nonisoenergetic and nonhomotropic flow specified by tabular data
4	user supplied subroutine called IVSUB

The parameter IVSTYP must be specified; there is no default value. The data needed to establish the initial-value surface are input through NAMELIST IVSL. For the subroutine IVSUB supplied with the program, the properties on the initial-value surface are calculated by superimposing two homotropic, spherical source flows, producing an approximation for a skewed inlet flow.

NP An integer specifying the number of mesh points along the positive y-axis (i.e., the  $X_2$  coordinate direction in the initial-value surface). The total number of points on the initial-value surface (and for each solution surface) depends on the value of NP and the number of planes of symmetry (NP/2 in NAMELIST IVSH). The maximum value which

NP can have is determined by the number of planes of symmetry and the dimensions of the arrays in NAMED COMMON SOLUTION and XRGLT. For array dimensions (2, N, N), the following relations apply:

<u>NP05</u> <u>planes of</u> <u>symmetry</u>	<u>NP</u> <u>(maximum)</u>	<u>NP</u> <u>(maximum)</u> <u>(for N=29)</u>	<u>total points on</u> <u>each solution plane</u>
0	$(N + 1)/2$	15	$(2NP - 1)^2$
1	$(N + 1)/2$	15	$NP(2NP - 1)$
2	$N - 2$	27	$(NP)^2$
3 or more	$N - 2$	27	$NP(NP + 1)/2$

The parameter NP must be specified; no default value is given. Experience to date has shown that NP should be at least 11 for most nozzle problems. In general, the value required to obtain accurate results will depend upon the gradients present in the flow, i. e., the larger the gradients, the greater the required number of points. It must also be considered that the number of points determines the computer time to solve a given problem. The time is proportional to the cube of NP. The CDC 6500 version of the program has built-in array dimensions of (2, 29, 29), and the IBM 7094 version has built-in array dimensions of (2, 19, 19). These values can be easily changed depending on the amount of storage available for expansion.

**XMAX** A parameter which specifies the value in inches along the  $X_1$  direction at which the integration is to be terminated. The  $X_1$  coordinate of the last integration plane will be automatically adjusted to coincide with this value. Normally this value will specify the end of the nozzle or passage being analyzed. The specified value for XMAX should be greater than the value of XIYS. A default value of 0.0 is specified, but this value will cause an error message to be generated and the job to be terminated.

**PRINTI** An integer parameter which controls the type of printed output as follows:

<u>value</u>	<u>printed output</u>
0	thrust parameters at each solution plane and flow properties at boundary points and interior points
1	thrust parameters at each solution plane and flow properties at boundary points
2	thrust parameters at each solution plane

A default value of 0 is specified.

PRINT2 An integer parameter which controls the quantity of printed output as follows:

<u>value</u>	<u>printed output</u>
1	at every point
2	at every other boundary and interior point
3	at every third boundary and interior point
N	at every Nth boundary and interior point

Note that the quantity of printout may be suppressed by the value of PRINT1. A default value of 1 is specified.

NSTART An integer parameter used when the capability to restart from tape is desired. NSTART controls the storage and retrieval of the solution values from the file tape (TAPE 7) as follows:

<u>Value</u>	<u>control</u>
negative	suppresses all tape operations
0	solution values written on tape
positive	solution values are retrieved from the file tape at solution surface NSTART and the integration will begin at surface NSTART + 1. New solution surfaces are written on the file tape.

When the restart capability is to be used, it is assumed that the file tape is mounted and the interlock set to permit writing on tape. The default value is -1. For some systems it may be necessary to change the tape number of the file tape.

ERROR A parameter used to specify the fractional convergence tolerance to be used in the integration subroutines. A default value of 0.0001 is specified. Experience has shown that smaller values generally do not improve the absolute accuracy of the solution for practical step sizes.

#### 4. NAMELIST WALSR

The data which are input through this namelist are designed specifically for the type of boundaries which are incorporated in the subroutine WALSUB supplied with the program. If another WALSUB subroutine is used, this namelist and the associated print routines in the subroutine READIN will need to be revised.

NSYMMY An integer parameter used to specify the symmetry of the flow boundaries as follows:

<u>value</u>	<u>boundary specifications</u>
1	axisymmetric contour
2	super-elliptical contour with two planes of symmetry
3	completely nonsymmetric, super-elliptical contour

The default value is 1.

YAXIS A parameter specifying the  $X_2$  coordinate of the axis of the nozzle contour. If planes of symmetry exist and are to be used to reduce the amount of computation, they must intersect at this axis. The default value is 0.0.

ZAXIS A parameter specifying the  $X_3$  coordinate of the axis of the nozzle contour. If planes of symmetry exist and are to be used to reduce the amount of computation, they must intersect at this axis. The default value is 0.0.

The next twenty-one parameters are one-dimensional arrays of up to four values each which are used in the description of the super-elliptic boundary described by the equation

$$\left(\frac{Y}{Y_0}\right)^{\text{EXPY}} + \left(\frac{Z}{Z_0}\right)^{\text{EXPZ}} = 1 \quad (1)$$

where  $Y_0$ ,  $Z_0$ , EXPY and EXPZ are functions of the axial coordinate  $X_1$ . For an axisymmetric contour (NSYMMY = 1) the variables EXPY = EXPZ = 2 and  $Y_0 = Z_0$  in each quadrant, where  $Y_0$  may be a function of  $X_1$ . For a super-elliptical contour with two planes of symmetry (NSYMMY = 2), the variables EXPY, EXPZ,  $Y_0$  and  $Z_0$  may each be functions of  $X_1$  but the functions are identical in both quadrants. For a completely nonsymmetric, super-elliptical boundary the variables EXPY and EXPZ may be different functions of  $X_1$  in each quadrant, and the intercepts  $Y_0$  and  $Z_0$  may be different functions of  $X_1$  in each coordinate plane. Although default values are specified for all the parameters, these values do not specify a meaningful contour.

The first seven parameters discussed below specify the intersection of the contour with the  $(X_1, X_2)$ ,  $(X_1, X_3)$ ,  $(X_1, -X_2)$ , and  $(X_1, -X_3)$  coordinate planes, respectively (i.e., the values for  $Y_0$  and  $Z_0$  as functions of the  $X_1$  coordinate). For an axisymmetric boundary, only the first value in each array needs to be input. For super-elliptical boundaries having two planes of symmetry (regardless of whether or not the flow has planes of symmetry), only the first two parameters of each array need to be input. For super-elliptical nozzles having one or zero planes of symmetry, all four parameters in each array must be input. The contour intersections with the

coordinate plane  $(X_1, X_2)$ ,  $(X_1, X_3)$ ,  $(X_1, -X_2)$  or  $(X_1, -X_3)$  consist of a circular arc joined tangentially to a parabola. Figure 2 illustrates the contour intersection with the  $(X_1, X_2)$  coordinate plane.

XT A one-dimensional array of up to four values for the axial locations in inches, of the centers of the circular arc portions of the contour intersections with the four coordinate reference planes (see Figure 2). The default values are 0.0.

RT A one-dimensional array for the distance, in inches, from the  $X_1$  axis to the minimum point on the circular arc sections of the contour intersections (i.e., the local throats, see Figure 2). The default values are 1.0.

RC A one-dimensional array for the radii of curvature, in inches, of the circular arc sections of the contour intersections (see Figure 2). The default values are 1.0.

THETAT A one-dimensional array for the slopes, in degrees, of the contour intersections at the point of tangency between the circular arcs and parabolas (see Figure 2). The default values are 0.0.

XE A one-dimensional array for  $X_1$  coordinates, in inches, of the exit points of the contour intersections (see Figure 2). The default values are 0.0.

RE A one-dimensional array for the radii, in inches, from the  $X_1$  axis to the exit points of the contour intersections (see Figure 2). For an axisymmetric, conical nozzle (i.e., THETAT = THETAE), RE does not have to be specified. The default values are 0.0.

THETA E A one-dimensional array for the slopes, in degrees, at the exit point of the contour intersections (see Figure 2). The default values are 0.0.

The remaining 14 parameters are one-dimensional arrays of up to four values each giving the variation of the two super-elliptical exponents (EXPY and EXPZ in Equation 1) with the  $X_1$  coordinate. Each quadrant of the super-elliptical contour may have separate functions corresponding to each of the four values of the arrays. Each set of 14 parameters is pertinent to one quadrant of the flow space. The first set corresponds to the space bounded by the  $(X_1, X_2)$  and  $(X_1, X_3)$  coordinate planes, the second set corresponds to the space bounded by the  $(X_1, X_3)$  and  $(X_1, -X_2)$  coordinate planes, the third set corresponds to the space bounded by the  $(X_1, -X_2)$  and  $(X_1, -X_3)$  coordinate planes, and the fourth set corresponds to the space bounded by the  $(X_1, -X_3)$  and  $(X_1, X_2)$  coordinate planes. For axisymmetric contours (i.e., NSYMMY = 1), the exponents are not used and need not be specified. For super-elliptical contours having two planes of symmetry only the first value in each of the 14 arrays needs to be specified. For general super-elliptical contours (NSYMMY = 2), all four values of each array must be specified. The variation in the exponents is described by two independent quadratic functions which are completely determined by specifying the exponents at three distinct points, and the derivative of

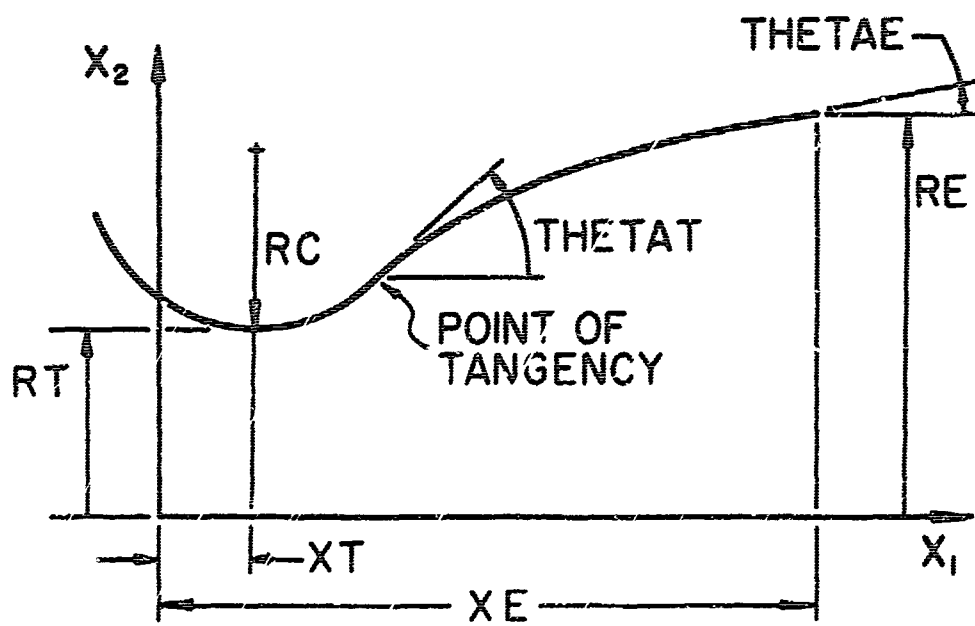


FIGURE 2. NOZZLE CONTOUR PARAMETERS

the exponent with respect to  $X_1$  at the center point. The first quadratic function describes the exponent between the first two points, and the second quadratic function describes the exponent between the second and third points. The default values are such that the exponents will be everywhere equal to 2.0.

XY1      One-dimensional arrays for the  $X_1$  coordinates, in inches,  
 XY2      of the three points used to specify the  $X_1$  variation of the  
 XY3      exponent EXPY in Equation 1.

EXPY1    One-dimensional arrays for the values of the super-elliptical  
 EXPY2    exponent EXPY in Equation 1 at the  $X_1$  positions specified  
 EXPY3    by XY1, XY2 and XY3, respectively.

DEDX12   A one-dimensional array for the values of the  $X_1$  derivative  
           of the super-elliptical exponent EXPY in Equation 1 evaluated  
           at  $X_1 = XY2$ .

XZ1      One-dimensional arrays for the  $X_1$  coordinates, in inches,  
 XZ2      of the three points used to specify the  $X_1$  variation of the  
 XZ3      exponent EXPZ in Equation 1.

EXPZ1    One-dimensional arrays for the values of the super-elliptical  
 EXPZ2    exponent EXPZ in Equation 1 at the  $X_1$  positions specified by  
 EXPZ3    XZ1, XZ2 and XZ3, respectively.

DEDXZ2   A one-dimensional array for the values of the  $X_1$  derivative of  
           the super-elliptical exponent EXPZ in Equation 1 evaluated at  
            $X_1 = XZ2$ .

## 5. NAMELIST ARQSB

The data which are input through this namelist are the ambient static pressure and the thermal and caloric equations of state for the fluid being considered. Two models for the equations of state are available. The first is a thermally and calorically perfect gas, and is chosen by specifying a value for GAMMA greater than 1.0. With this model, variations in stagnation pressure and enthalpy can be accounted for in the flow field. The second is a gas with frozen or equilibrium chemical composition in which the

pressure, temperature, density and speed of sound are one-dimensional functions of Mach number specified by tabular data. This option is implemented when GAMMA is not specified, or when the specified value of GAMMA is one or less. With this option the flow must be homentropic and isopenergetic (i.e., stagnation pressure and enthalpy both uniform throughout the flow).

PAMB     The ambient static pressure in psia. The default value is 0.0.

GAMMA     The specific heat ratio for a thermally and calorically perfect gas. The default value is 0.0.

RGAS     The gas constant for the thermally perfect gas in units of (ft-lbf)/(lbm-°R). The default value is 1.0.

If the thermally and calorically perfect gas model is used, no further values need be specified in NAMELIST ARQSB. The next five parameters are one-dimensional arrays of up to 30 values each for the tabular thermodynamic data. The Mach number, MTAB, is the independent variable for the tabular data, and its values must increase monotonically and cover the range of Mach numbers which will be encountered in the integration process. Normally this range should extend from a Mach number slightly less than 1.0 to a sufficiently high Mach number for the particular problem. Tabular values of the dependent variable arrays must correspond to the appropriate value of Mach number in MTAB.

MTAB     A one-dimensional array of up to 30 values for the Mach number, which is the independent variable for the tabular data. No default values are specified.

PTAB     A one-dimensional array of the values of absolute static pressure, in psia, which correspond to the values of MTAB. No default values are specified.

ATAB     A one-dimensional array of the values of the speed of sound, in ft/sec, which correspond to the values of MTAB. No default values are specified.

ROTAB     A one-dimensional array of the values of density, in lbm/ft<sup>3</sup>, which correspond to the values of MTAB. No default values are specified.

TTAB     A one-dimensional array of the values of static temperature, in °R, which correspond to the values of MTAB. Since the static temperature is not used in the computations, these values are only used to determine the temperature to be printed out. They can be omitted if desired. The default values are 0.0.

The variables PTAB, ATAB, ROTAB and TTAB are dimensioned in the program as (30,2). The actual parameter values are stored in the two-dimensional array with the second subscript equal to 1. The locations specified by the second subscript equal to 2 are used in curve fitting of these parameters.

## 6. NAMELIST IVSL

The data which are input through this namelist are used to establish the initial-value surface. The type of initial-value surface is selected by the choice of the parameter for IVSTYP in NAMELIST CNTRL.

**NPØS** An integer parameter specifying the number of common planes of symmetry for both the initial data and the boundary contour. Values of 0, 1, 2, 3, 4, 5, 6, 7, or 8 may be specified. A default value of 0 is specified.

**XIVS** The  $X_1$  coordinate of the planar initial-value surface in inches. When a source flow initial-value surface is specified (i.e., IVSTYP = 2), the source flow spherical surface is positioned symmetrically about the  $X_1$ -axis so that the spherical surface intersects the nozzle wall where the wall slope and source flow angle are equal. The  $X_1$  coordinate of the intersection of the source flow surface with the  $X_1$ -axis is then set equal to XIVS, so no input value is required. The properties on a plane perpendicular to the  $X_1$ -axis located at  $X_1 = XIVS$  are then calculated using the properties of the source flow. When IVSTYP = 1, 2 or 3, XIVS must be input to locate the initial-value surface. The default value is 0.0.

**YCIVS** The  $X_2$  and  $X_3$  coordinates of the central point of the initial-value surface in inches. Normally these should be the coordinates of the area centroid of the initial-value surface. For axisymmetric nozzles and super-elliptical nozzles having two planes of symmetry (i.e., NSYMMY = 1 or 2), these coordinates should coincide with YAXIS and ZAXIS, respectively. The default values are 0.0.

The following three parameters must be specified for initial-value surfaces specified by IVSTYP = 1 (uniform flow), IVSTYP = 2 (source flow) and IVSTYP = 4 (double source flow surface routine IVSUB which is supplied with the program).

**MCIVS** The Mach number at the central point (YCIVS, ZCIVS) of the initial-value surface. This value must be greater than unity. No default value is specified.

**PTCIVS** The stagnation pressure in psia at the central point of the initial-value surface. No default value is specified.

**HCIVS** The stagnation enthalpy in Btu/lbm at the central point of the initial-value surface. No default value is specified.

The following four parameters are applicable to the types of initial-value surfaces as indicated.

THECIV (For IVSTYP = 1) The pitch angle, in degrees, of the velocity vector for a uniform flow. The pitch angle is the angle between the projection of the velocity vector on the  $(X_1, X_2)$  coordinate plane and the  $X_1$  axis. The default value is 0.0.

PHICIV (For IVSTYP = 1) The yaw angle, in degrees, of the velocity vector for a uniform flow. The yaw angle is the angle between the velocity vector and its projection on the  $(X_1, X_2)$  coordinate plane. The default value is 0.0.

ALPSRC (For IVSTYP = 2 or 4) The spherical source half-angle, in degrees, of the initial-value surface source flow. No default value is specified.

BETSRC (For IVSTYP = 4) A parameter specifying the second source offset angle, in degrees, in the double source model. No default value is specified.

The following six parameters are one-dimensional arrays of up to 30 values which are used to specify tabular initial-value surface properties for IVSTYP = 3 (i.e., for an axisymmetric, nonisoenergetic and nonhomentropic initial-value surface). These parameters do not need to be specified for IVSTYP = 1, 2 or 4. The initial-value surface is a plane parallel to the  $(X_2, X_3)$  coordinate plane and intersecting the  $X_1$  axis at XIVS. The data points must extend from the center of the initial-value surface (first point) to the outer contour (last point) but need not be equally spaced. The initial-value surface used by the program for computing the flow is constructed by fitting a third degree spline to the tabular data and interpolating for the variables at the desired points. Since the flow is axisymmetric, it is assumed that values are specified along the  $X_2$  coordinate direction, and these values are rotated around the  $X_1$  axis to cover the entire initial-value surface.

RIVS A one-dimensional array of up to 30 values for the radial coordinate values ( $X_2$  values) at which the flow variables are to be specified on the initial-value surface. The first value must be 0.0 and the last value must coincide with the radius of the contour at  $X_1 = XIVS$  to within  $\pm 0.0001$  inches. The dimensions are inches. No default values are specified.

MIVS A one-dimensional array of the Mach numbers corresponding to the table of radial coordinates RIVS. No default values are specified.

PTIVS A one-dimensional array of stagnation pressures, in psia, corresponding to the table of radial coordinates RIVS. No default values are specified.

HIVS A one-dimensional array of stagnation enthalpies, in Btu/lbm, corresponding to the table of radial coordinates RIVS. No default values are specified.

THETIV A one-dimensional array of the pitch angles, in degrees, corresponding to the table of radial coordinates RIVS. The pitch angle is defined as the angle between the projection of the velocity vector on the  $(X_1, X_2)$  coordinate plane and the  $X_1$  axis (assuming the tabular data are specified along the  $X_2$  coordinate direction). No default values are specified.

PSIIV A one-dimensional array of the swirl angles, in degrees, corresponding to the table of radial coordinates RIVS. The swirl angle is defined as the angle between the projection of the velocity vector on the  $(X_2, X_3)$  coordinate plane and the  $X_2$  axis (assuming the tabular data are specified along the  $X_2$  coordinate direction). No default values are specified.

The variables PTIVS and HIVS are dimensioned in the program as (30,2). The actual parameter values are stored in the two-dimensional array with the second subscript equal to 1. The locations specified by the second subscript equal to 2 are used in curve fitting of these parameters.

## SECTION V

### SAMPLE CASES

In this Section, eight sample cases are presented to illustrate the application of the computer program to several exhaust nozzle problems. All of the options of the program are illustrated by at least one of the sample cases. However, due to the large number of possible combinations of initial-value surface types, flow chemistry possibilities, and nozzle geometries, all of the possible combinations are not considered. In each sample case, the problem to be analyzed is discussed, the necessary input data are developed, a figure showing the input cards is presented, and selected portions of the computer output are illustrated. The first four sample cases consider axisymmetric, contoured nozzles with various initial-value line options and gas chemistries, the next two cases illustrate the super-elliptical contour option, and the last two cases demonstrate the use of tapes for storing the solution and restarting from tape. The input data discussions follow the order in which the input parameters are presented in Section IV. In each of the eight cases, the TITLE CARD, which is always the first card in a data deck, identifies the sample case number. In all eight of the sample cases, the number of points (i.e. NP in NAMELIST CNTRL) is set at 7. In general, it is recommended that NP be of the order of 11 to obtain satisfactory accuracy. However, computing time is proportional to the cube of NP, so the lower value was employed strictly to reduce the running time of the sample cases. The objective of presenting the sample cases is to illustrate the preparation of data decks, and not to demonstrate accuracy. The running time on both the CDC 6500 and IBM 7094 computers for all sample cases is included in each sample case discussion.

#### 1. SAMPLE CASE 1

The first four sample cases all consider the same axisymmetric, contoured nozzle with various combinations of initial-value surface types and gas chemistries. For sample case 1, a homentropic, spherical, source flow initial-value line is selected with 7 points along the positive y-axis. Thus, IVSTYP = 2 and NP = 7. The nozzle flow field is desired out to a length of 10 inches, so XMAX = 10.0. All calculated points are to be printed, so PRINT1 and PRINT2 are left at their default values of 0 and 1 respectively. No tape operations are desired, so NSTART is left at its default value of -1. The default value of 0.0001 for the fractional convergence tolerance, ERROR, is chosen, so no value is input. This completes the specification of NAMELIST CNTRL.

Since the nozzle is axisymmetric, NSYMMY retains its default value of 1. The nozzle axis is aligned with the flow field axis by allowing YAXIS and ZAXIS to remain at the default values of 0.0. Since the nozzle is axisymmetric, only the first value of each array specifying the contour needs to be specified. The throat is located at  $X_1 = 0.0$ , the throat radius is 1.0 inch, and the throat radius of curvature is 1.0 inch. Thus, XT, YT and RC are left at their default values. The inflection point between the circular arc throat region and the parabolic contour occurs at an angle of  $36.0^\circ$ , so

THETAT = 36.0. The nozzle exit is specified by XE = 10.0, RE = 4.0 and THETA E = 13.0. A general parabola is fit between the inflection point and the nozzle exit. The remaining parameters in the wall specification are employed only for super-elliptical contours, so they need not be considered here. This completes the specification of NAMELIST WALSB L. These same specifications will be used in sample cases 2, 3 and 4.

For all of the sample cases, the ambient pressure will be set at zero. Thus, the default value will be employed. Sample cases 1, 3, 4, 5 and 6 will all consider a thermally and calorically perfect gas with  $\gamma = 1.4$  and  $R = 53.3 \text{ (ft-lbf)/(lbm-}^\circ\text{R)}$ . Thus, GAMMA = 1.4 and RGAS = 53.3. No other values are required for this option. This completes the specification of NAMELIST ARG SBL.

The last set of parameters specifies the initial-value surface properties. Sample cases 1, 2 and 3 all employ a source flow initial-value surface (i.e., IVSTYP = 2 in NAMELIST CNTRL L). Sample cases 1 and 2 are identical, both having 4 planes of symmetry; thus NPQS = 4. This value of NPQS results in a  $45^\circ$  sector of the flow field being evaluated. The remaining  $315^\circ$  sector can be obtained by reflection. For a source flow initial-value surface, XIVS does not need to be specified. YCIVS and ZCIVS are left at their default values of 0.0 to agree with YAXIS and ZAXIS as specified in NAMELIST WALSB L. The Mach number is 1.10, the uniform stagnation pressure is 1000.0 psia, and the uniform stagnation enthalpy is 1255.0. Thus, MCIVS = 1.10, PTCIVS = 1000.0, and HCIVS = 1255.0. The only remaining parameter required to specify the source flow is the source angle, which is chosen as  $10.0^\circ$ . Thus, ALPSRC = 10.0. None of the remaining parameters are required for this option. This completes specification of NAMELIST IVSL.

Figure 3 presents a listing of the data deck for sample case 1. Note that only the parameters required by the various options are specified, and parameters whose default values are correct are not specified. Should it be desirable to specify all parameters actually employed even if the value chosen is the default value, this can be done. The omission of parameters with satisfactory default values was made purely to save time in the preparation of the data deck.

Figure 4 is a complete listing of the output from sample case 1. The first two pages describe the problem being considered, the third page contains the initial-value surface data, and the remaining pages contain the data at succeeding solution planes. The first two pages are self-explanatory. The format of the remaining pages is nearly identical, the only differences being in the mass flow, thrust and moment data. On the initial-value surface, the actual calculated mass flow rate, thrust, and moment values are listed. The thrust is specified in rectangular components, and signs are chosen so that the values shown are the forces exerted on the fluid by the nozzle walls and planes of symmetry. To obtain forces acting on the walls and planes of symmetry, the signs must be reversed. The moments are evaluated with respect to the point (0.0, YAXIS, ZAXIS). The I and J integers are coordinates of the characteristic network, and are described in Volume I. Y and Z are the rectangular coordinates of the streamline intersections with the solution plane located at the X value specified at the top of the page. M is the Mach number and Q is the velocity magnitude. P, RHQ and T are the

pressure, density and temperature, respectively, of the fluid. U, V and W are the rectangular components of the velocity in the X, Y and Z directions, respectively. P and H are the stagnation pressure and enthalpy, respectively. On solution surfaces, the mass flow rate is not written out. Instead, the ratio of the initial-value surface mass flow rate to the locally evaluated mass flow rate is given. All thrusts and moments have been multiplied by this ratio in an attempt to cancel out errors due to integration over the entire surface. These errors are some indication of the accuracy of the overall scheme; however, the accuracies of the individual properties at each solution point are not dependent on these overall values, since these values are not used in the second-order integration scheme. The last line of data identifies the point in the flow which controls the step size so as to satisfy the Courant-Fredrichs-Lewy stability criterion. The safety factor is discussed in Volume I, and DELTA X is the computed step size to the next solution plane.

Sample case 1 required 91 seconds of central processor time and 122 seconds of peripheral processor time on the CDC 6500, and 190 seconds of central memory time on the IBM 7094.

SAMPLE CASE NO. 1  
\$CNTRL           IVSTYP=2,  
NP=7,  
XMAX=10.0       \$  
\$WALSBL           THETAT=36.0,  
XE=10.0,  
RE=4.0,  
THETA=13.0       \$  
\$AROSBL           GAMMA=1.4,  
RGAS=53.3        \$  
\$IVSL             NPOS=4,  
MCIVS=1.10,  
PTCIVS=1000.0,  
HCIVS=1255.0,  
ALPSRC=10.0     \$

Figure 3. Data Deck 1

# THREE-DIMENSIONAL ANALYSIS OF SUPERSONIC NOZZLE FLOW

## ABSTRACT

THIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERSITY JET PROPULSION CENTER BY V. H. RAMSOL AS A PART OF THE REQUIREMENTS OF AF CONTRACT NUMBER F33615-67-C-1068. THE CONTRACT WAS SPONSORED BY THE AERO PROPULSION LABORATORY WRIGHT PATTERSON AFB, OHIO AND PRINCIPAL INVESTIGATORS FOR PURDUE UNIVERSITY WERE PROFESSORS H. DOYLE THOMPSON AND J. C. HOFFMAN. THE EQUATIONS OF MOTION FOR A THREE-DIMENSIONAL SUPERSONIC FLOW ARE SOLVED USING A NUMERICAL METHOD OF CHARACTERISTICS HAVING SECOND-ORDER ACCURACY. THE FLOW VARIABLES MUST BE SPECIFIED OVER A SPACE-LIKE INITIAL VALUE SURFACE WHICH ADJOINS THE NOZZLE BOUNDARIES. THE NOZZLE GEOMETRY IS SPECIFIED BY MEANS OF THE SUBROUTINE WALSUB. THE NOZZLE MAY HAVE PLANES OF SYMMETRY AND THE THERMODYNAMIC PROPERTIES OF THE GAS ARE DETERMINED BY MEANS OF THE SUBROUTINE ARJSSUP.

## MAJOR ASSUMPTIONS

THE GASDYNAMIC MODEL IS BASED ON THE FOLLOWING ASSUMPTIONS. 1. CONTINUUM, 2. INVISCID, 3. STEADY, 4. STRICTLY ADIABATIC, 5. FROZEN OR EQUILIBRIUM CHEMICAL COMPOSITION, AND 6. SMOOTH INITIAL DATA AND BOUNDARIES.

## JOB TITLE

SAMPLE CASE NO. 1

## THERMODYNAMIC MODEL

A CALORICALLY AND THERMALLY PERFECT GAS IS SPECIFIED AND IS CHARACTERIZED BY THE FOLLOWING VALUES  
SPECIFIC HEAT RATIO = 1.40000 AND GAS CONSTANT = 53.30000 (FT-LBF/LBM-DEG R)

## FLOW GEOMETRY

THE FLOW HAS 4 PLANES OF SYMMETRY PASSING THROUGH THE POINT-

X = 0. (IN) Y = 0. (IN) Z = 0. (IN)

THE COMPONENTS OF THE OUTER NORMALS TO THE FIRST TWO PLANES ARE -

NX1 = 0. NY1 = 0. NZ1 = -1.000000

NX2 = 0. NY2 = -0.707107 NZ2 = 0.707107

Figure 4. Sample Case 1 Output

# NOZZLE GEOMETRY

AXISYMMETRIC CIRCLE-PARABOLA CONTOURED NOZZLE HAVING THE FOLLOWING PARAMETERS

THROAT AND AXIS COORDINATES

XI = 0. (IN) YC = 0. (IN) ZC = 0. (IN)

CONTOUR PARAMETERS

RT = 1.0000 (IN) RC = 1.0000 (IN) XE = 10.0000 (IN) RE = 4.0000

THETAT = 36.0000 (DEG) THETA E = 13.0000 (DEG)

## TYPE OF INITIAL DATA SURFACE

SOURCE FLOW IS USED TO ESTABLISH THE INITIAL VALUES. THE SOURCE ANGLE IS SPECIFIED AND THE SOURCE POINT IS LOCATED ON THE NOZZLE AXIS SUCH THAT THE INITIAL FLOW IS TANGENT TO THE NOZZLE WALL. THE PROPERTIES OF THE SOURCE ARE ESTABLISHED BY SPECIFICATION OF THE PROPERTIES AT THE AXIAL POINT OF THE INITIAL VALUE SURFACE.

SOURCE POINT

SOURCE ANGLE = 10.000 (DEG) X = -5.5838 (IN) Y = 0. (IN) Z = 0. (IN)

REFERENCE POINT

X = 0.1736 (IN) Y = 0. (IN) Z = 0. (IN)

M = 1.1000 PT = 1000.00(LBF/IN\*\*2) H = 1255.0(BTU/LBM)

Figure 4. (Continued)

INITIAL DATA - X = 0.1736 (IN)  
 THRUST PARAMETERS  
 CROSS SECTION AREA = 0.4036 (IN\*\*2) MASS FLOW = 2.8764 (LBM/SEC)  
 XTHRUST = -498.94 (LBF) YTHRUST = -34.57 (LBF) ZTHRUST = -14.32 (LBF)  
 XMOMT = -0.30 (FT-LBF) YMOMT = -122.77 (FT-LBF) ZMOMT = 296.38 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y	Z	M	Q	P	RMC	T	U	V	M	PT	M
		(IN)	(IN)	(FT/SEC)	(LBF/IN2)	(LBF/IN2)	(LBM/FT3)	(DFG RI)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN2)	(BTU/LBM)
1	1	0.7178	0.7178	1.228	3816.6	397.35	0.2669E 00	4021.6	3758.6	468.6	468.6	1000.0	1255.0
1	2	0.8054	0.6180	1.228	3816.6	397.35	0.2669E 00	4021.6	3758.6	525.8	403.5	1000.0	1255.0
1	3	0.8792	0.5076	1.228	3816.6	397.35	0.2669E 00	4021.6	3758.6	574.0	311.4	1000.0	1255.0
1	4	0.9379	0.3885	1.228	3816.6	397.35	0.2669E 00	4021.6	3758.6	612.1	251.6	1000.0	1255.0
1	5	0.9806	0.2628	1.228	3816.6	397.35	0.2669E 00	4021.6	3758.6	640.2	171.5	1000.0	1255.0
1	6	1.0065	0.1325	1.228	3816.6	397.35	0.2669E 00	4021.6	3758.6	657.1	86.5	1000.0	1255.0
1	7	1.0142	0.	1.228	3816.6	397.35	0.2669E 00	4021.6	3758.6	662.7	0.	1000.0	1255.0
2	2	0.6180	0.6180	1.202	3754.4	411.08	0.2735E 00	4060.8	3711.9	396.4	398.4	1000.0	1255.0
2	3	0.7071	0.5137	1.202	3754.4	411.08	0.2735E 00	4060.8	3711.9	455.9	311.2	1000.0	1255.0
2	4	0.7787	0.3968	1.202	3754.4	411.08	0.2735E 00	4060.8	3711.9	502.1	255.8	1000.0	1255.0
2	5	0.8312	0.2701	1.202	3754.4	411.08	0.2735E 00	4060.8	3711.9	535.9	174.1	1000.0	1255.0
2	6	0.8632	0.1367	1.202	3754.4	411.08	0.2735E 00	4060.8	3711.9	556.5	88.1	1000.0	1255.0
2	7	0.8740	0.	1.202	3754.4	411.08	0.2735E 00	4060.8	3711.9	563.5	0.	1000.0	1255.0
3	3	0.5076	0.5076	1.175	3688.2	425.82	0.2805E 00	4101.9	3659.8	322.7	312.7	1000.0	1255.0
3	4	0.5969	0.3988	1.175	3688.2	425.82	0.2805E 00	4101.9	3659.8	379.4	251.5	1000.0	1255.0
3	5	0.6632	0.2747	1.175	3688.2	425.82	0.2805E 00	4101.9	3659.8	421.6	174.1	1000.0	1255.0
3	6	0.7041	0.1400	1.175	3688.2	425.82	0.2805E 00	4101.9	3659.8	447.5	89.0	1000.0	1255.0
3	7	0.7178	0.	1.175	3688.2	425.82	0.2805E 00	4101.9	3659.8	456.3	0.	1000.0	1255.0
4	4	0.3885	0.3885	1.148	3621.7	440.70	0.2874E 00	4142.4	3605.3	243.3	243.3	1000.0	1255.0
4	5	0.4758	0.2747	1.148	3621.7	440.70	0.2874E 00	4142.4	3605.3	298.0	172.0	1000.0	1255.0
4	6	0.5307	0.1422	1.148	3621.7	440.70	0.2874E 00	4142.4	3605.3	332.3	89.0	1000.0	1255.0
4	7	0.5494	0.	1.148	3621.7	440.70	0.2874E 00	4142.4	3605.3	344.0	0.	1000.0	1255.0
5	5	0.2628	0.2628	1.124	3561.2	454.33	0.2938E 00	4178.6	3553.8	162.2	162.2	1000.0	1255.0
5	6	0.3433	0.1422	1.124	3561.2	454.33	0.2938E 00	4178.6	3553.8	211.9	87.6	1000.0	1255.0
5	7	0.3716	0.	1.124	3561.2	454.33	0.2938E 00	4178.6	3553.8	229.4	0.	1000.0	1255.0
6	6	0.1325	0.1325	1.107	3516.3	464.48	0.2984E 00	4205.0	3514.5	60.9	80.4	1000.0	1255.0
6	7	0.1874	0.	1.107	3516.3	464.48	0.2984E 00	4205.0	3514.5	114.4	0.	1000.0	1255.0
7	7	0.	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0

XSTEP REGULATION PARAMETERS

LIMITING POINT I = 6 AND J = 6 SAFETY FACTOR = 0.64000 DELTA X = 0.0405

UNDRFLOW AT 62337 IN MQ  
 UNDRFLOW AT 62337 IN MQ  
 UNDRFLOW AT 62337 IN MQ  
 UNDRFLOW AT 62337 IN MQ  
 UNDRFLOW AT 62361 IN MQ

Figure 4. (Continued)

SOLUTION SURFACE - X = 0.2141 (IN) PLANE 1														
THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)														
CROSS SECTION AREA= C-410C (IN**2) MASS FLOW RATE RATIO = 1.00421														
XTTHRUST = -501.57 (LBF) YTHRUST = -37.56 (LBF) ZTHRUST = -15.56 (LBF)														
XMCMT = 0.00 (FT-LBF) YMCMT = -122.79 (FT-LBF) ZMCMT = 296.45 (FT-LBF)														
BOUNDARY AND INTERIOR FLOW PARAMETERS														
I	J	X (IN)	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHC (LBM/FT3)	T (DIG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN2)	H (RTU/LBM)
1	1	0.7235	0.7235	1.357	1.357	4112.6	333.75	0.2357E 00	3826.1	4017.2	622.7	622.7	1000.0	1255.0
1	2	0.8118	0.6229	1.357	1.357	4112.6	333.75	0.2357E 00	3826.1	4017.2	622.7	622.7	1000.0	1255.0
1	3	0.8861	0.5116	1.357	1.357	4112.5	333.76	0.2357E 00	3826.1	4017.1	622.7	622.7	1000.0	1255.0
1	4	0.9453	0.3916	1.357	1.357	4112.5	333.77	0.2357E 00	3826.1	4017.1	622.7	622.7	1000.0	1255.0
1	5	0.9883	0.2648	1.357	1.357	4112.5	333.76	0.2357E 00	3826.1	4017.1	622.7	622.7	1000.0	1255.0
1	6	1.0144	0.1336	1.357	1.357	4112.6	333.75	0.2357E 00	3826.1	4017.1	622.7	622.7	1000.0	1255.0
1	7	1.0232	0.0000	1.357	1.357	4112.6	333.75	0.2357E 00	3826.1	4017.2	622.7	622.7	1000.0	1255.0
2	1	0.6224	0.6224	1.247	1.247	3862.2	387.35	0.2621E 00	3992.4	3818.5	409.4	409.4	1000.0	1255.0
2	2	0.7120	0.5113	1.247	1.247	3862.2	387.35	0.2621E 00	3992.4	3818.5	409.4	409.4	1000.0	1255.0
2	3	0.7842	0.3946	1.247	1.247	3862.2	387.35	0.2621E 00	3992.4	3818.5	409.4	409.4	1000.0	1255.0
2	4	0.8371	0.2720	1.247	1.247	3862.2	387.35	0.2621E 00	3992.4	3818.5	409.4	409.4	1000.0	1255.0
2	5	0.8693	0.1377	1.247	1.247	3862.2	387.35	0.2621E 00	3992.4	3818.5	409.4	409.4	1000.0	1255.0
2	6	0.8801	0.0000	1.247	1.247	3862.2	387.35	0.2621E 00	3992.4	3818.5	409.4	409.4	1000.0	1255.0
3	1	0.5112	0.5112	1.225	1.225	3809.3	358.96	0.2677E 00	4026.2	3780.1	391.1	391.1	1000.0	1255.0
3	2	0.6011	0.4010	1.225	1.225	3809.3	358.95	0.2677E 00	4026.2	3780.1	391.1	391.1	1000.0	1255.0
3	3	0.6679	0.2766	1.225	1.225	3809.3	358.95	0.2677E 00	4026.2	3780.1	391.1	391.1	1000.0	1255.0
3	4	0.7090	0.1410	1.225	1.225	3809.3	358.95	0.2677E 00	4026.2	3780.1	391.1	391.1	1000.0	1255.0
3	5	0.7229	0.0000	1.225	1.225	3809.3	358.96	0.2677E 00	4026.2	3780.1	391.1	391.1	1000.0	1255.0
4	1	0.3912	0.3912	1.205	1.205	3759.6	409.94	0.2730E 00	4057.6	3780.1	470.4	470.4	1000.0	1255.0
4	2	0.4792	0.2766	1.205	1.205	3759.6	409.93	0.2729E 00	4057.6	3780.1	470.4	470.4	1000.0	1255.0
4	3	0.5344	0.1432	1.205	1.205	3759.6	409.93	0.2729E 00	4057.6	3780.1	470.4	470.4	1000.0	1255.0
4	4	0.5533	0.0000	1.205	1.205	3759.6	409.94	0.2730E 00	4057.6	3780.1	470.4	470.4	1000.0	1255.0
5	1	0.2646	0.2646	1.188	1.188	3718.2	419.10	0.2773E 00	4083.3	3710.7	355.9	355.9	1000.0	1255.0
5	2	0.3457	0.1432	1.188	1.188	3718.2	419.11	0.2773E 00	4083.3	3710.7	355.9	355.9	1000.0	1255.0
5	3	0.3742	0.0000	1.188	1.188	3718.2	419.10	0.2773E 00	4083.3	3710.7	355.9	355.9	1000.0	1255.0
6	1	0.1334	0.1334	1.176	1.176	3691.0	425.16	0.2802E 00	4100.1	3689.1	118.9	118.9	1000.0	1255.0
6	2	0.1887	0.0000	1.176	1.176	3691.0	425.11	0.2802E 00	4100.1	3689.1	118.9	118.9	1000.0	1255.0
7	1	0.0000	-0.2000	1.173	1.173	3681.4	427.34	0.2812E 00	4106.1	3681.4	0.0	0.0	1000.0	1255.0
XSTEP REGULATION PARAMETERS														
LIMITING POINT I = 6 AND J = 6 SAFETY FACTOR = 0.70400 DELTA X = 0.0680														

Figure 4. (continued)

SOLUTION SURFACE -															X =	0.2821 (IN)		PLANE 2						
THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)																								
CROSS SECTION AREA=															0.424C (IN*2)		MASS FLOW RATE RATIO =		.01135					
XTHRUST =															-506.01 (LBF)		YTHRUST =		-43.59 (LBF)		ZTHRUST =		-18.06 (LBF)	
XMCMT =															-0.00 (FT-LBF)		YMCMT =		-122.67 (FT-LBF)		ZMCMT =		296.14 (FT-LBF)	
BOUNDARY AND INTERIOR FLOW PARAMETERS																								
I	J	X (IN)	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHU (LBF/FT3)	T (DEG K)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/FT3)	PI (LBF/FT3)	PM (LBF/FT3)									
1	1	0.7358	0.7358	1.556	4528.6	250.92	0.1922E 00	3526.6	4344.6	903.4	403.4	1000.0	1000.0	1000.0	1000.0									
1	2	0.8750	0.6335	1.556	4528.5	250.94	0.1922E 00	3526.7	4344.5	1013.9	777.4	1000.0	1000.0	1000.0	1000.0									
1	3	0.9012	0.5203	1.556	4528.2	250.99	0.1923E 00	3526.9	4344.2	1106.8	638.0	1000.0	1000.0	1000.0	1000.0									
1	4	0.9614	0.3982	1.556	4527.8	251.06	0.1923E 00	3527.2	4343.9	1179.7	490.0	1000.0	1000.0	1000.0	1000.0									
1	5	1.0052	0.2693	1.556	4528.2	250.99	0.1923E 00	3526.9	4344.2	1233.8	331.5	1000.0	1000.0	1000.0	1000.0									
1	6	1.0317	0.1358	1.556	4528.5	250.94	0.1922E 00	3526.7	4344.5	1266.6	167.2	1000.0	1000.0	1000.0	1000.0									
1	7	1.0406	-0.0000	1.556	4528.6	250.92	0.1922E 00	3526.6	4344.6	1777.7	-0.0	1000.0	1000.0	1000.0	1000.0									
2	2	0.6300	0.6300	1.345	4086.5	339.21	0.2384E 00	3843.9	4031.4	473.0	473.0	1000.0	1000.0	1000.0	1000.0									
2	3	0.7208	0.5237	1.345	4087.1	339.10	0.2384E 00	3843.5	4032.0	593.8	354.6	1000.0	1000.0	1000.0	1000.0									
2	4	0.7938	0.4045	1.346	4087.9	338.92	0.2383E 00	3842.9	4033.0	636.5	203.2	1000.0	1000.0	1000.0	1000.0									
2	5	0.8474	0.2753	1.346	4087.9	338.10	0.2384E 00	3843.5	4032.0	660.7	102.7	1000.0	1000.0	1000.0	1000.0									
2	6	0.8800	0.1394	1.345	4086.5	339.21	0.2384E 00	3843.9	4031.4	664.9	-0.0	1000.0	1000.0	1000.0	1000.0									
2	7	0.8910	-0.0000	1.345	4086.5	339.21	0.2384E 00	3843.9	4031.4	664.9	-0.0	1000.0	1000.0	1000.0	1000.0									
3	3	0.5171	0.5171	1.292	3967.1	364.62	0.2510E 00	3924.0	3936.9	345.5	345.5	1000.0	1000.0	1000.0	1000.0									
3	4	0.6081	0.4063	1.292	3967.1	364.62	0.2510E 00	3924.0	3936.9	406.3	271.2	1000.0	1000.0	1000.0	1000.0									
3	5	0.6757	0.2799	1.292	3967.1	364.62	0.2510E 00	3924.0	3936.9	451.1	186.4	1000.0	1000.0	1000.0	1000.0									
3	6	0.7173	0.1427	1.292	3967.1	364.62	0.2510E 00	3924.0	3936.9	479.1	95.2	1000.0	1000.0	1000.0	1000.0									
3	7	0.7313	0.0000	1.292	3967.1	364.62	0.2510E 00	3924.0	3936.9	488.6	0.0	1000.0	1000.0	1000.0	1000.0									
4	4	0.3950	0.3950	1.276	3929.4	372.74	0.2550E 00	3948.8	3911.9	262.0	262.0	1000.0	1000.0	1000.0	1000.0									
4	5	0.4847	0.2799	1.276	3929.4	372.74	0.2550E 00	3948.8	3911.9	320.9	185.2	1000.0	1000.0	1000.0	1000.0									
4	6	0.5407	0.1449	1.276	3929.4	372.75	0.2550E 00	3948.8	3911.9	357.8	95.5	1000.0	1000.0	1000.0	1000.0									
4	7	0.5597	0.0000	1.276	3929.4	372.75	0.2550E 00	3948.8	3911.9	370.5	0.0	1000.0	1000.0	1000.0	1000.0									
5	5	0.2677	0.2677	1.263	3859.0	379.33	0.2582E 00	3968.6	3891.1	175.5	175.5	1000.0	1000.0	1000.0	1000.0									
5	6	0.3497	0.1449	1.263	3859.0	379.34	0.2582E 00	3968.7	3891.1	229.3	95.0	1000.0	1000.0	1000.0	1000.0									
5	7	0.3785	0.0000	1.263	3859.0	379.34	0.2582E 00	3968.6	3891.1	248.2	0.0	1000.0	1000.0	1000.0	1000.0									
6	6	0.1350	0.1350	1.255	3879.1	383.66	0.2603E 00	3981.5	3677.1	67.9	87.9	1000.0	1000.0	1000.0	1000.0									
6	7	0.1509	0.0000	1.255	3879.1	383.66	0.2603E 00	3981.5	3677.1	124.3	0.0	1000.0	1000.0	1000.0	1000.0									
7	7	-0.0000	-0.0000	1.252	3872.0	383.72	0.2611E 00	3986.1	3672.0	-0.0	-0.0	1000.0	1000.0	1000.0	1000.0									
XSTEP REGULATION PARAMETERS																								
LIMITING POINT I = 3 AND J = 7															SAFETY FACTOR =		0.77440		DELTA X =		0.0960			

Figure 4. (Continued)

SOLUTION SURFACE -														
K = 0.3781 (IN) PLANE 3														
THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)														
CRCS SECTION AREA= 0.4519 (IN**2) MASS FLOW RATE RATIO = 1.02330														
XTHRUST = -512.05 (LBF) YTHRUST = -54.12 (LBF) ITHRUST = -22.44 (LBF)														
XCMY = -0.31 (FT-LBF) YCMY = -121.62 (FT-LBF) ZCMY = 293.64 (FT-LBF)														
BOUNDARY AND INTERIOR FLOW PARAMETERS														
I	J	Y	Z	M	Q	P	RHO	T	U	V	W	X	PT	H
1	1	0.7596	0.7596	1.854	5057.6	160.74	0.1355E 00	3102.5	4683.9	1352.8	1352.8	1352.8	1000.0	1255.0
1	2	0.8523	0.5339	1.854	5059.5	160.76	0.1395E 00	3102.6	4683.8	1518.5	1163.7	1163.7	1000.0	1255.0
1	3	0.9303	0.5371	1.854	5060.5	160.10	0.1394E 00	3101.7	4684.8	1638.0	955.4	955.4	1000.0	1255.0
1	4	0.9875	0.4112	1.854	5059.6	160.23	0.1395E 00	3102.4	4684.0	1766.3	735.2	735.2	1000.0	1255.0
1	5	1.0316	0.2781	1.854	5060.6	160.08	0.1394E 00	3101.6	4684.8	1847.8	497.5	497.5	1000.0	1255.0
1	6	1.0651	0.1492	1.854	5059.6	160.24	0.1395E 00	3102.5	4683.9	1898.7	250.8	250.8	1000.0	1255.0
1	7	1.0742	-0.0000	1.854	5059.6	160.23	0.1395E 00	3102.5	4683.9	1913.2	-0.0	-0.0	1000.0	1255.0
2	2	0.6427	0.6427	1.501	4418.3	272.00	0.2036E 00	3608.8	4320.5	626.4	626.4	626.4	1000.0	1255.0
2	3	0.7352	0.5243	1.502	4420.8	271.51	0.2034E 00	3607.0	4331.4	712.6	524.2	524.2	1000.0	1255.0
2	4	0.8097	0.4127	1.504	4425.3	270.64	0.2029E 00	3603.7	4336.3	783.8	406.8	406.8	1000.0	1255.0
2	5	0.8644	0.2807	1.505	4425.4	270.62	0.2029E 00	3603.6	4336.3	842.1	268.6	268.6	1000.0	1255.0
2	6	0.8977	0.1421	1.502	4420.7	271.52	0.2034E 00	3607.0	4331.3	874.6	133.1	133.1	1000.0	1255.0
2	7	0.9089	-0.0000	1.501	4418.2	272.00	0.2036E 00	3608.9	4328.5	885.9	-0.1	-0.1	1000.0	1255.0
3	3	0.5258	0.5256	1.385	4174.0	320.98	0.2292E 00	3783.7	4138.5	384.1	384.2	384.2	1000.0	1255.0
3	4	0.6183	0.4131	1.385	4174.2	320.94	0.2292E 00	3783.5	4138.7	450.8	307.8	307.8	1000.0	1255.0
3	5	0.6870	0.2846	1.385	4175.3	320.72	0.2291E 00	3782.8	4139.7	501.4	210.2	210.2	1000.0	1255.0
3	6	0.7293	0.1421	1.385	4174.2	320.95	0.2292E 00	3783.6	4138.7	532.9	104.6	104.6	1000.0	1255.0
3	7	0.7436	-0.0000	1.385	4174.0	320.99	0.2292E 00	3783.7	4138.5	545.3	-0.0	-0.0	1000.0	1255.0
4	4	0.4022	0.4022	1.356	4109.9	334.32	0.2360E 00	3828.0	4091.6	273.3	273.3	273.3	1000.0	1255.0
4	5	0.4926	0.2844	1.356	4109.8	334.33	0.2360E 00	3828.0	4091.6	334.7	193.2	193.2	1000.0	1255.0
4	6	0.5494	0.1472	1.356	4109.8	334.34	0.2360E 00	3828.0	4091.6	373.3	100.1	100.1	1000.0	1255.0
4	7	0.5688	0.0000	1.356	4109.8	334.33	0.2360E 00	3828.0	4091.6	386.5	0.0	0.0	1000.0	1255.0
5	5	0.2720	0.2720	1.345	4085.6	339.41	0.2382E 00	3844.5	4077.3	183.6	183.6	183.6	1000.0	1255.0
5	6	0.3554	0.1477	1.345	4085.5	339.42	0.2382E 00	3844.6	4077.3	239.8	99.3	99.3	1000.0	1255.0
5	7	0.3847	0.0000	1.345	4085.5	339.42	0.2382E 00	3844.6	4077.3	259.6	0.0	0.0	1000.0	1255.0
6	6	0.1372	0.1372	1.338	4069.5	342.79	0.2402E 00	3855.4	4067.4	92.1	92.1	92.1	1000.0	1255.0
6	7	0.1940	0.0000	1.338	4069.5	342.80	0.2402E 00	3855.4	4067.4	130.3	-0.0	-0.0	1000.0	1255.0
7	7	-0.0000	-0.0000	1.335	4063.7	344.01	0.2406E 00	3859.3	4063.7	-0.0	-0.0	-0.0	1000.0	1255.0
KSTEP REGULATION PARAMETERS														
LIFTING POINT I = 3 AND J = 7 SAFETY FACTOR = 0.85184 DELTA X = 0.1220														

Figure 4. (Continued)

SOLUTION SURFACE - X = 8.1011 (IN) PLANE 19

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA = 5.3481 (IN\*\*2) MASS FLOW RATE RATIO = 0.99613

XTHRUST = -644.18 (LBF) YTHRUST = -81.28 (LBF) ZTHRUST = -33.80 (LBF)

XCMPT = -0.62 (FT-LBF) YCMPT = -129.06 (FT-LBF) ZCMPT = 797.02 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHC (LBF/FT3)	T (OFG. N)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN2)	H (BTU/LBM)
1	1	2.6133	4.073	6949.0	5.98	0.1332E-01	1212.4	1136.9	1136.9	1136.9	1136.9	1000.0	1255.0
1	2	2.9313	2.2509	4.074	6949.4	5.97	0.1331E-01	1211.9	6760.8	1276.4	972.9	1000.0	1255.0
1	3	3.1975	1.8533	4.077	6950.7	5.94	0.1327E-01	1210.4	6762.1	1389.9	803.1	1000.0	1255.0
1	4	3.4099	1.4252	4.080	6951.5	5.93	0.1324E-01	1209.3	6762.9	1480.0	625.8	1000.0	1255.0
1	5	3.5669	0.9675	4.081	6952.2	5.91	0.1322E-01	1207.6	6763.6	1548.4	436.1	1000.0	1255.0
1	6	3.6634	0.4882	4.080	6951.8	5.92	0.1323E-01	1209.2	6763.1	1592.8	224.2	1000.0	1255.0
1	7	3.6958	0.0000	4.080	6951.5	5.93	0.1324E-01	1209.4	6762.9	1606.4	0.0	1000.0	1255.0
2	2	2.3096	2.3089	4.103	6960.7	5.75	0.1295E-01	1198.8	6826.5	962.2	961.9	1000.0	1255.0
2	3	2.6369	1.9161	4.105	6961.5	5.73	0.1293E-01	1197.9	6826.0	1093.1	797.1	1000.0	1255.0
2	4	2.9046	1.4754	4.109	6963.2	5.70	0.1287E-01	1195.9	6830.8	1202.3	617.7	1000.0	1255.0
2	5	3.0985	1.0091	4.111	6963.0	5.69	0.1285E-01	1195.2	6831.2	1284.4	423.7	1000.0	1255.0
2	6	3.2210	0.5122	4.110	6963.5	5.69	0.1286E-01	1195.5	6830.2	1338.8	215.6	1000.0	1255.0
2	7	3.2670	0.0000	4.108	6962.6	5.71	0.1289E-01	1196.6	6828.3	1361.2	0.7	1000.0	1255.0
3	3	1.9677	1.9674	4.151	6979.0	5.40	0.1238E-01	1177.5	6497.5	751.6	751.7	1000.0	1255.0
3	4	2.3086	1.5361	4.153	6979.9	5.38	0.1236E-01	1176.5	6490.5	866.4	592.8	1000.0	1255.0
3	5	2.5638	1.0522	4.155	6980.7	5.37	0.1233E-01	1175.6	6490.8	969.2	411.3	1000.0	1255.0
3	6	2.7206	0.5799	4.154	6980.2	5.37	0.1235E-01	1176.1	6499.6	1037.3	208.5	1000.0	1255.0
3	7	2.7699	0.0002	4.149	6978.2	5.41	0.1241E-01	1178.4	6496.5	1064.7	0.1	1000.0	1255.0
4	4	1.6050	1.6050	4.231	7010.1	4.84	0.1145E-01	1141.4	6499.7	531.2	531.3	1000.0	1255.0
4	5	1.9612	1.1226	4.231	7008.6	4.86	0.1150E-01	1143.1	6497.1	634.2	368.6	1000.0	1255.0
4	6	2.1837	0.5858	4.230	7008.3	4.87	0.1151E-01	1143.4	6498.6	723.7	175.4	1000.0	1255.0
4	7	2.2649	0.0001	4.224	7006.3	4.91	0.1151E-01	1146.1	6495.6	751.8	-0.1	1000.0	1255.0
5	5	1.1822	1.1824	4.464	7087.7	3.62	0.0930E-02	1050.2	7069.1	362.5	362.7	1000.0	1255.0
5	6	1.5485	0.6190	4.453	7084.2	3.67	0.0939E-02	1054.4	7066.2	472.4	174.3	1000.0	1255.0
5	7	1.6737	-0.0001	4.447	7082.2	3.65	0.0946E-02	1056.7	7063.7	511.2	-0.2	1000.0	1255.0
6	6	0.6449	0.6450	4.844	7197.3	2.27	0.6677E-02	819.7	7187.9	260.6	260.7	1000.0	1255.0
6	7	0.9112	-0.0001	4.839	7196.2	2.29	0.6702E-02	921.1	7186.9	365.1	-0.1	1000.0	1255.0
7	7	0.0000	0.0000	5.046	7247.7	1.79	0.5631E-02	859.2	7247.7	0.0	0.0	1000.0	1255.0

STEP REGULATION PARAMETERS

LIMITING POINT I = 1 AND J = 7 SAFETY FACTOR = 0.9732 DELTA X = 1.5690

Figure 4. (Continued)

SOLUTION SURFACE - X = 10.0000 (IN) PLANE 20

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA = 6.2649 (IN\*\*2) MASS FLOW RATE RATIO = 0.99997

XTHRUST = -648.91 (LBF) YTHRUST = -10.25 (LBF) ZTHRUST = -31.76 (LBF)

XMOMT = -0.62 (FT-LBF) VMOMT = -354.27 (FT-LBF) ZMOMT = 858.60 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y (IN)	Z (IN)	M (FT/SEC)	Q (LBF/IN2)	P (LBF/IN2)	RHO (LBF/FT3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBI/IN2)	M (BTU/LBM)
1	1	2.8285	2.6284	4.291	7030.1	4.50	0.1087E-01	1117.9	6849.9	1118.3	1118.2	1000.0	1255.0
1	2	3.1727	2.4340	4.292	7030.4	4.50	0.1087E-01	1117.6	6850.2	1255.3	761.9	1000.0	1255.0
1	3	3.4605	2.0043	4.293	7031.6	4.48	0.1083E-01	1116.2	6851.4	1367.5	795.0	1000.0	1255.0
1	4	3.6899	1.5442	4.294	7032.6	4.46	0.1081E-01	1115.2	6852.2	1456.5	617.4	1000.0	1255.0
1	5	3.8598	1.0497	4.300	7033.2	4.45	0.1078E-01	1114.5	6852.9	1523.6	426.6	1000.0	1255.0
1	6	3.9647	0.5364	4.301	7033.4	4.45	0.1078E-01	1114.2	6853.0	1566.9	219.3	1000.0	1255.0
1	7	4.0000	0.0001	4.301	7033.7	4.45	0.1078E-01	1114.1	6853.1	1582.2	0.0	1000.0	1255.0
2	2	2.4800	2.4883	4.319	7039.7	4.34	0.1060E-01	1105.6	6913.9	937.2	774.2	1000.0	1255.0
2	3	2.9406	2.0447	4.321	7040.6	4.33	0.1058E-01	1105.7	6916.1	1065.1	600.3	1000.0	1255.0
2	4	3.1265	1.5905	4.326	7042.2	4.30	0.1052E-01	1103.7	6916.1	1171.6	413.7	1000.0	1255.0
2	5	3.3391	1.0884	4.328	7042.6	4.29	0.1052E-01	1103.1	6918.2	1252.3	212.0	1000.0	1255.0
2	6	3.4704	0.5526	4.328	7042.8	4.29	0.1052E-01	1103.0	6917.3	1306.7	0.0	1000.0	1255.0
2	7	3.5211	0.0005	4.326	7042.2	4.30	0.1053E-01	1103.7	6915.7	1328.8	0.0	1000.0	1255.0
3	3	2.1053	2.1050	4.361	7054.2	4.21	0.1020E-01	1089.7	6980.5	718.9	718.8	1000.0	1255.0
3	4	2.4671	1.6444	4.365	7055.4	4.10	0.1017E-01	1088.3	6983.7	829.1	565.0	1000.0	1255.0
3	5	2.7415	1.1266	4.368	7056.3	4.08	0.1014E-01	1087.1	6984.1	928.7	390.5	1000.0	1255.0
3	6	2.9108	0.5778	4.366	7055.8	4.09	0.1016E-01	1087.7	6982.3	996.2	200.5	1000.0	1255.0
3	7	2.9761	0.0002	4.360	7053.7	4.12	0.1021E-01	1090.2	6979.2	1022.8	0.1	1000.0	1255.0
4	4	1.6490	1.6491	4.430	7076.8	3.77	0.9588E-02	1063.0	7044.2	479.9	480.0	1000.0	1255.0
4	5	2.0740	1.1872	4.430	7076.9	3.77	0.9588E-02	1063.0	7045.7	573.9	331.9	1000.0	1255.0
4	6	2.3117	0.6172	4.428	7076.3	3.78	0.9603E-02	1063.7	7044.1	655.4	159.6	1000.0	1255.0
4	7	2.5943	-0.0001	4.421	7073.9	3.82	0.9647E-02	1064.5	7040.8	681.2	-0.1	1000.0	1255.0
5	5	1.2413	1.2415	4.605	7130.9	3.04	0.8209E-02	999.0	7120.6	268.5	268.7	1000.0	1255.0
5	6	1.6244	0.6491	4.594	7129.2	3.06	0.8252E-02	1001.1	7119.6	342.4	139.7	1000.0	1255.0
5	7	1.7573	-0.0001	4.591	7126.9	3.09	0.8308E-02	1003.8	7116.8	379.3	-0.1	1000.0	1255.0
6	6	0.6802	0.6803	4.948	7224.0	2.01	0.6111E-02	887.7	7221.7	141.3	141.4	1000.0	1255.0
6	7	0.9408	-0.0001	4.946	7223.5	2.01	0.6122E-02	886.3	7220.8	197.0	-0.1	1000.0	1255.0
7	7	0.0001	0.0000	5.188	7279.9	1.52	0.5013E-02	820.1	7279.9	0.0	0.0	1000.0	1255.0

STEP REGULATION PARAMETERS

LIMITING POINT I = 1 AND J = 7 SAFETY FACTOR = 1.07506 DELTA X = 2.0230

EXECUTION TIME 190.2 SECS

Figure 4. (Continued)

## 2. SAMPLE CASE 2

The second sample case is identical to sample case 1 in every respect except the specification of the thermodynamic properties of the gas. Thus, NAMELISTS CNTRL, WALSB, and IVSL are identical to those developed in sample case 1, and are not discussed further here. For sample case 2, the flow is assumed to be isoenergetic and homentropic, with the gas properties specified by tabular data. It should be kept in mind that the tabular property option can only be employed for isoenergetic, homentropic flows. This option is employed by specifying GAMMA as one or less. Thus, the default value of 0.0 will automatically specify the tabular data option. For the present case, a table of 30 values of M, p, a, P and T was generated for a gas having  $\gamma = 1.20$  and  $R = 53.3 \text{ (ft-lbf)/(lbm-}^\circ\text{R)}$ . In other words, the thermodynamic data used in sample case 1 by specifying  $\gamma$  and R are also employed in sample case 2 in tabular form. Thus, the results of these two sample cases should be identical except for small differences due to using interpolated values of the thermodynamic properties. The tabular values of MTAB, PTAB, ATAB, ROTAB and TTAB are presented in Figure 5. Those values complete the specification of NAMELIST ARSBL.

Figure 5 is a complete listing of the data deck for sample case 2. Figure 6 presents selected portions of the output from sample case 2. By comparing with the results of sample case 1, it can be seen that essentially identical results are obtained. Sample case 2 required 82 seconds of central processor time and 122 seconds of peripheral processor time on the CDC 6500, and 173 seconds of central memory time on the IBM 7094.

```

SAMPLE CASE NO. 2
$CNTRL      IVSTYP=2,
NP=7,
XMAX=10.0   $
$WALSBL     THETAT=36.0,
XE=10.0,
RE=4.0,
THETAE=13.0 $
$AROSBL     HYAB=1.0,1.1,1.2,1.3,1.4,1.5,1.6,1.7,1.8,1.9,2.0,2.2,2.4,2.6,
2.8,3.0,3.2,3.4,3.6,3.8,4.0,4.2,4.4,4.6,4.8,5.0,5.2,5.5,5.8,6.1,
PTAB=528.3,468.4,412.4,360.9,314.2,272.4,235.3,202.6,174.0,149.2,127.8,93.5,
68.4,50.1,36.8,27.2,20.2,15.1,12.1,8.6,6.2,5.5,4.6,3.9,3.1,2.3,1.8,
1.890,1.501,1.075,0.779,0.572,
ATAB=3164.1,3110.1,3054.1,2996.5,2937.8,2878.4,2828.8,2759.2,2700.0,2641.3,
2583.5,2470.7,2362.8,2260.1,2162.9,2071.4,1985.3,1904.6,1828.6,1757.8,1691.3,
1628.9,1570.3,1515.3,1463.6,1415.0,1369.2,1305.4,1246.8,1192.4,
ROTAB=0.3425,0.3143,0.2870,0.2609,0.2364,0.2134,0.1922,0.1727,0.1549,
0.1388,0.1243,0.0994,0.0795,0.0636,0.0513,0.0411,0.0333,0.0270,0.0221,
0.0181,0.0149,0.0119,0.0103,0.0086,0.0072,0.0061,0.0051,0.0040,
0.0032,0.0026,
TTAB=4166.7,4025.8,3882.0,3735.9,3560.0,3448.3,3306.9,3168.6,3033.9,2903.8,
2777.8,2540.7,2373.4,2125.9,1947.0,1785.7,1640.4,1509.7,1392.0,1286.0,1190.5,
1104.2,1026.3,955.6,891.6,833.3,780.3,709.2,646.9,592.3   $
$IVSL      NPOS=4,
MCIVS=1.10,
PTCIVS=1000.0,
MCIVS=1255.0,
ALPSRC=10.0 $

```

Figure 5. Data Deck 2

# THREE-DIMENSIONAL ANALYSIS OF SUPERSONIC NOZZLE FLOW

## ABSTRACT

THIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERSITY JET PROPULSION CENTER BY V. M. RANSUM AS A PART OF THE REQUIREMENTS OF AIR CONTRACT NUMBER F33615-67-C-1048. THE CONTRACT WAS SPONSORED BY THE AERO PROPULSION LABORATORY WRIGHT PATTERSON AFB, OHIO AND PRINCIPAL INVESTIGATORS FOR PURDUE UNIVERSITY WERE PROFESSORS H. DOYLE THOMPSON AND JOE D. HOFFMAN.

THE EQUATIONS OF MOTION FOR A THREE-DIMENSIONAL SUPERSONIC FLOW ARE SOLVED USING A NUMERICAL METHOD OF CHARACTERISTICS HAVING SECOND-ORDER ACCURACY. THE FLOW VARIABLES MUST BE SPECIFIED ON A SPACE-LIKE INITIAL VALUE SURFACE WHICH ADJOINS THE NOZZLE BOUNDARIES. THE NOZZLE GEOMETRY IS SPECIFIED BY PLANS OF THE SUBROUTINE MALSUB. THE NOZZLE MAY HAVE PLANS OF SYMMETRY AND THE THERMODYNAMIC PROPERTIES OF THE GAS ARE DETERMINED BY MEANS OF THE SUBROUTINE AVALSER.

## PAPER ASSUMPTIONS

1. THE GASDYNAMIC MODEL IS BASED ON THE FOLLOWING ASSUMPTIONS. 1. CONTINUUM, 2. INVISCID, 3. STEADY, 4. STRICTLY ADIABATIC, 5. FROZEN OR EQUILIBRIUM CHEMICAL COMPOSITION, AND 6. SMOOTH INITIAL DATA AND BOUNDARIES.

## JOB TITLE

SAMPLE CASE NO. 2

## THERMODYNAMIC MODEL

A PONEUTROPIC FLOW IS ASSUMED. THE GAS PROPERTIES ARE INPUT AS TABULAR FUNCTIONS OF MACH NUMBER.

M	P (LBM/IN**2)	A (FT/SEC)	RHC (LBM/FT**3)	T (DEG R)
1.000	528.300	3164.10	C.1425E 00	4166.7
1.100	468.400	3110.10	C.1143E 00	4023.8
1.200	412.400	3054.10	C.02870E 00	3882.0
1.300	366.900	2996.50	C.2609E 00	3735.9
1.400	314.200	2937.80	C.2.64E 00	3560.0
1.500	272.400	2878.40	C.2134E 00	3448.3
1.600	235.300	2828.80	C.1922E 00	3306.5
1.700	202.600	2759.20	C.1727E 00	3168.6
1.800	174.000	2700.00	C.1550E 00	3033.9
1.900	149.200	2641.30	C.1389E 00	2903.6
2.000	127.800	2583.20	C.1243E 00	2777.8
2.200	93.500	2470.70	C.945E-01	2540.7
2.400	68.400	2362.80	C.7953E-01	2323.4
2.600	50.100	2260.10	C.6369E-01	2125.9
2.800	36.860	2162.90	C.5113E-01	1947.0

Figure 6. Sample Case 2 Output

FLOW GEOMETRY								
THE FLOW HAS 4 PLANES OF SYMMETRY PASSING THROUGH THE POINT-								
X =	0.	(IN)	Y =	0.	(IN)	Z =	0.	(IN)
THE COMPONENTS OF THE OUTER NORMALS TO THE FIRST TWO PLANES ARE-								
NX1 =	0.		NY1 =	0.		NZ1 =	-1.000000	
NX2 =	0.		NY2 =	-0.707107		NZ2 =	0.707107	

M	P (LBF/IN**2)	A (FT/SEC)	RHC (LBM/FT**3)	T (DEG R)
3.000	27.220	2071.40	C.4119E-01	1785.7
3.200	20.220	1985.30	C.3331E-01	1640.4
3.400	15.120	1904.60	C.2707E-01	1509.7
3.600	11.380	1828.80	C.2210E-01	1392.0
3.800	8.628	1757.80	C.1813E-01	1286.0
4.000	6.586	1691.30	C.1495E-01	1190.5
4.200	5.062	1628.90	C.1239E-01	1104.2
4.400	.917	1570.30	C.1031E-01	1026.3
4.600	3.052	1515.30	C.8629E-02	955.6
4.800	2.594	1463.60	C.7255E-02	891.6
5.000	1.890	1415.00	C.6128E-02	833.3
5.200	1.501	1369.20	C.5198E-02	780.3
5.500	1.715	1305.40	C.4094E-02	709.2
5.800	0.779	1246.80	C.3255E-02	646.9
6.100	0.772	1192.40	C.2609E-02	592.3

Figure 6. (Continued)

# NOZZLE GEOMETRY

AXISYMMETRIC CIRCLE-PARABOLA CONTOURED NOZZLE HAVING THE FOLLOWING PARAMETERS

## THROAT AND AXIS COORDINATES

XT = 0. (IN) YC = 0. (IN) ZC = 0. (IN)

## CONTOUR PARAMETERS

RT = 1.0000 (IN) RC = 1.0000 (IN) XE = 10.0000 (IN) RE = 4.0000

THETAT = 36.0000 (DEG) THETAET = 13.0000 (DEG)

## TYPE OF INITIAL DATA SURFACE

SOURCE FLOW IS USED TO ESTABLISH THE INITIAL VALUES. THE SOURCE ANGLE IS SPECIFIED AND THE SOURCE POINT IS LOCATED ON THE NOZZLE AXIS SUCH THAT THE INITIAL FLOW IS TANGENT TO THE NOZZLE WALL. THE PROPERTIES OF THE SOURCE ARE ESTABLISHED BY SPECIFICATION OF THE PROPERTIES AT THE AXIAL POINT OF THE INITIAL VALUE SURFACE.

## SOURCE POINT

SOURCE ANGLE = 10.000 (DEG) X = -5.5838 (IN) Y = 0. (IN) Z = 0. (IN)

## REFERENCE POINT

X = 0.1736 (IN) Y = 0. (IN) Z = 0. (IN)

M = 1.1000 PT = 1000.00(LBF/IN\*\*2) H = 1255.0(FTU/LBM)

Figure 6. (Continued)

INITIAL DATA - X = 0.1736 (IN)

# THRUST PARAMETERS

CROSS SECTION AREA = 0.4036 (IN<sup>2</sup>) MASS FLOW = 2.9442 (LBM/SEC)  
 XTHRUST = -499.19 (LBF) YTHRUST = -34.60 (LBF) ZTHRUST = -14.33 (LBF)  
 XMOMT = -0.20 (FT-LBF) YMOMT = -122.83 (FT-LBF) ZMOMT = 296.53 (FT-LBF)

# BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	X	Y	Z	M	Q	P	RHC	T	U	V	W	PT	N
1	1	0.7178	0.7178	1.228	1.228	3731.1	3731.1	0.2795E 00	3844.3	3674.4	458.1	1000.0	1000.0	1255.0
1	2	0.8054	0.8054	1.228	1.228	3731.1	3731.1	0.2795E 00	3844.3	3674.4	514.0	1000.0	1000.0	1255.0
1	3	0.8792	0.8792	1.228	1.228	3731.1	3731.1	0.2795E 00	3844.3	3674.4	561.1	1000.0	1000.0	1255.0
1	4	0.9379	0.9379	1.228	1.228	3731.1	3731.1	0.2795E 00	3844.3	3674.4	596.6	1000.0	1000.0	1255.0
1	5	0.9806	0.9806	1.228	1.228	3731.1	3731.1	0.2795E 00	3844.3	3674.4	623.8	1000.0	1000.0	1255.0
1	6	1.0065	1.0065	1.228	1.228	3731.1	3731.1	0.2795E 00	3844.3	3674.4	647.9	1000.0	1000.0	1255.0
1	7	1.0152	1.0152	1.228	1.228	3731.1	3731.1	0.2795E 00	3844.3	3674.4	669.6	1000.0	1000.0	1255.0
2	1	0.7071	0.7071	1.203	1.203	3671.1	3671.1	0.2863E 00	3878.4	3629.6	449.9	1000.0	1000.0	1255.0
2	2	0.7187	0.7187	1.203	1.203	3671.1	3671.1	0.2863E 00	3878.4	3629.6	490.9	1000.0	1000.0	1255.0
2	3	0.8312	0.8312	1.203	1.203	3671.1	3671.1	0.2863E 00	3878.4	3629.6	524.0	1000.0	1000.0	1255.0
2	4	0.8632	0.8632	1.203	1.203	3671.1	3671.1	0.2863E 00	3878.4	3629.6	544.2	1000.0	1000.0	1255.0
2	5	0.8740	0.8740	1.203	1.203	3671.1	3671.1	0.2863E 00	3878.4	3629.6	551.0	1000.0	1000.0	1255.0
2	6	0.8969	0.8969	1.176	1.176	3606.6	3606.6	0.2936E 00	3916.0	3578.9	315.5	1000.0	1000.0	1255.0
2	7	0.9041	0.9041	1.176	1.176	3606.6	3606.6	0.2936E 00	3916.0	3578.9	371.0	1000.0	1000.0	1255.0
3	1	0.7041	0.7041	1.140	1.140	3606.6	3606.6	0.2936E 00	3916.0	3578.9	412.3	1000.0	1000.0	1255.0
3	2	0.7178	0.7178	1.140	1.140	3606.6	3606.6	0.2936E 00	3916.0	3578.9	437.6	1000.0	1000.0	1255.0
3	3	0.7385	0.7385	1.148	1.148	3541.1	3541.1	0.3009E 00	3954.9	3525.0	446.2	1000.0	1000.0	1255.0
3	4	0.7558	0.7558	1.148	1.148	3541.1	3541.1	0.3009E 00	3954.9	3525.0	462.2	1000.0	1000.0	1255.0
3	5	0.7747	0.7747	1.148	1.148	3541.1	3541.1	0.3009E 00	3954.9	3525.0	479.1	1000.0	1000.0	1255.0
3	6	0.7944	0.7944	1.148	1.148	3541.1	3541.1	0.3009E 00	3954.9	3525.0	490.9	1000.0	1000.0	1255.0
3	7	0.8128	0.8128	1.124	1.124	3481.3	3481.3	0.3076E 00	3990.4	3474.1	158.5	1000.0	1000.0	1255.0
3	8	0.8333	0.8333	1.124	1.124	3481.3	3481.3	0.3076E 00	3990.4	3474.1	168.2	1000.0	1000.0	1255.0
3	9	0.8516	0.8516	1.107	1.107	3437.5	3437.5	0.3125E 00	4016.2	3435.7	79.1	1000.0	1000.0	1255.0
3	10	0.8744	0.8744	1.107	1.107	3437.5	3437.5	0.3125E 00	4016.2	3435.7	111.8	1000.0	1000.0	1255.0
3	11	0.8974	0.8974	1.100	1.100	3421.1	3421.1	0.3143E 00	4025.8	3421.1	0.0	1000.0	1000.0	1255.0

# X-REP REGULATION PARAMETERS

LIMITING POINT I = 6 AND J = 6 SAFETY FACTOR = 0.54000 DELTA X = 0.0405

UNDRFLCM AT 62337 IN MQ

UNDRFLCM AT 62337 IN MQ

UNDRFLCM AT 62337 IN MQ

UNDRFLCM AT 62337 IN MQ

UNDRFLCM AT 62361 IN MQ

Figure 6. (Continued)

SOLUTION SURFACE - X = 10.0000 (IN) PLANE 20													
THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)													
CRCS SECTION AREA=		6.2649 (IN**2)		MASS FLOW RATE RATIO =		1.00267							
XTHRUST =		-649.43 (LBF)		YTHRUST =		-76.38 (LBF)		ZTHRUST =		-31.81 (LBF)			
XCMOM =		-0.64 (FT-LBF)		YCMOM =		-353.40 (FT-LBF)		ZCMOM =		856.70 (FT-LBF)			
BOUNDARY AND INTERIOR FLOW PARAMETERS													
I	J	Y	Z	M	Q	P	RMC	T	U	V	W	PT	H
1	1	2.8285	2.8284	4.294	6874.1	4.48	0.1136E-01	1066.8	6697.9	1093.4	1093.4	1000.0	1255.0
1	2	3.1727	2.4359	4.294	6874.4	4.48	0.1135E-01	1066.5	6698.2	1221.5	940.9	1000.0	1255.0
1	3	3.4605	2.0062	4.298	6875.1	4.46	0.1132E-01	1065.2	6699.3	1331.2	777.3	1000.0	1255.0
1	4	3.6900	1.5441	4.300	6876.3	4.45	0.1129E-01	1064.2	6700.1	1424.1	604.0	1000.0	1255.0
1	5	3.8598	1.0496	4.302	6877.0	4.44	0.1127E-01	1063.5	6700.7	1489.6	417.5	1000.0	1255.0
1	6	3.9647	0.5304	4.302	6877.1	4.43	0.1127E-01	1063.3	6700.9	1532.1	214.7	1000.0	1255.0
1	7	4.0000	0.0001	4.303	6877.2	4.43	0.1127E-01	1063.3	6700.9	1547.0	0.0	1000.0	1255.0
2	2	2.4891	2.4884	4.321	6883.5	4.33	0.1107E-01	1056.0	6700.4	916.6	916.6	1000.0	1255.0
2	3	2.8407	2.0649	4.324	6884.3	4.32	0.1105E-01	1055.1	6702.7	1041.7	757.5	1000.0	1255.0
2	4	3.1267	1.5906	4.329	6885.9	4.29	0.1100E-01	1053.2	6704.5	1144.9	587.1	1000.0	1255.0
2	5	3.3383	1.0882	4.330	6886.4	4.28	0.1099E-01	1052.6	6704.6	1224.4	404.8	1000.0	1255.0
2	6	3.4711	0.5523	4.330	6886.4	4.29	0.1099E-01	1052.7	6704.6	1271.6	207.2	1000.0	1255.0
2	7	3.5210	0.0005	4.328	6885.4	4.29	0.1100E-01	1053.3	6702.5	1298.5	0.0	1000.0	1255.0
3	3	2.1056	2.1053	4.364	6897.6	4.10	0.1055E-01	1039.8	6825.5	703.4	703.4	1000.0	1255.0
3	4	2.4675	1.6447	4.368	6898.8	4.08	0.1052E-01	1038.5	6828.6	811.4	552.9	1000.0	1255.0
3	5	2.7420	1.1267	4.370	6899.7	4.07	0.1059E-01	1037.4	6829.0	908.6	382.0	1000.0	1255.0
3	6	2.9112	0.5777	4.369	6899.2	4.07	0.1061E-01	1037.9	6827.2	974.5	196.4	1000.0	1255.0
3	7	2.9761	0.0002	4.363	6897.2	4.11	0.1067E-01	1040.3	6824.2	1000.1	0.0	1000.0	1255.0
4	4	1.6995	1.6996	4.433	6919.8	3.76	0.1001E-01	1014.2	6887.8	469.9	470.0	1000.0	1255.0
4	5	2.0748	1.1877	4.433	6919.8	3.76	0.1001E-01	1014.2	6889.3	562.0	325.1	1000.0	1255.0
4	6	2.3124	0.6175	4.431	6919.2	3.77	0.1002E-01	1014.8	6887.7	641.6	156.3	1000.0	1255.0
4	7	2.3986	-0.0001	4.424	6916.9	3.80	0.1009E-01	1017.5	6884.5	668.4	-0.1	1000.0	1255.0
5	5	1.2418	1.2421	4.608	6972.8	3.02	0.8565E-02	952.8	6962.8	263.6	263.6	1000.0	1255.0
5	6	1.6254	0.6496	4.6.3	6971.1	3.04	0.8669E-02	954.7	6961.7	336.2	136.7	1000.0	1255.0
5	7	1.7577	-0.0001	4.595	6968.9	3.07	0.8667E-02	957.3	6959.0	372.1	-0.1	1000.0	1255.0
6	6	0.6805	0.6806	4.953	7663.8	2.00	0.6370E-02	846.4	7061.1	139.3	139.4	1000.0	1255.0
6	7	0.9810	-0.0001	4.951	7063.4	2.00	0.6381E-02	847.0	7060.7	194.1	-0.1	1000.0	1255.0
7	7	0.0001	0.0000	5.193	7118.4	1.51	0.5228E-02	782.1	7116.4	0.0	0.0	1000.0	1255.0
XSTEP REGULATION PARAMETERS													
LIMITING POINT I = 1 AND J = 7		SAFETY FACTOR =		1.07508		DELTA X =		2.0230					
EXECUTION TIME		173.4 SECS											

Figure 6. (Continued)

### 3. SAMPLE CASE 3

The third sample case is identical to the first in every respect except no planes of symmetry are assumed, and the Mach number at the center of the source flow initial-value surface is increased to 1.5 to simulate a supersonic start condition such as could occur in a scramjet. In addition, the centerline of the nozzle is offset from the coordinate axes to illustrate that option. Thus, NAMELISTS CNTRL and ARQSBL are the same as in sample case 1. The values of YAXIS = 1.0 and ZAXIS = 1.0 have been added to NAMELIST WALSBL. In NAMELIST IVSL, NPQS is allowed to have its default value of 0 for no planes of symmetry, MCIVS has been changed to 1.50, and YCIVS and ZCIVS have been specified as 1.0. These changes complete the specification of data deck 3.

Figure 7 is a listing of data deck 3. Figure 8 presents selected portions of the output from sample case 3. This sample case required 494 seconds of central processor time and 129 seconds of peripheral processor time on the CDC 6500, and 886 seconds of central memory time on the IBM 7094.

SAMPLE CASE NO. 3  
SCNTRLL IVSTYP=2,  
NP=7,  
XMAX=10.0 \$  
SWALSBL YAXIS=1.0,ZAXIS=1.0,  
THETAT=36.0,  
XE=10.0,  
RE=4.0,  
THETA E=13.0 \$  
\$AROSBL GAMMA=1.4,  
RGAS=53.3 \$  
\$IVSL YCIVS=1.0,  
ZCIVS=1.0,  
MCIVS=1.50,  
PTCIVS=1000.0,  
HCIVS=1255.0,  
ALPSRC=10.0 \$

Figure 7. Data Deck 3

# THREE-DIMENSIONAL ANALYSIS OF SUPERSONIC NOZZLE FLOW

## TRACT

THIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERSITY JET PROPULSION CENTER BY V. M. RANSON AS A PART OF THE REQUIREMENTS OF AF CONTRACT NUMBER F33615-67-C-1028. THE CONTRACT WAS SPONSORED BY THE AERO PROPULSION LABORATORY WRIGHT PATTERSON AFB, OHIO AND PRINCIPAL INVESTIGATORS FOR PURDUE UNIVERSITY WERE PROFESSORS H. DOYLE THOMPSON AND JOE D. MUFFMAN. THE EQUATIONS OF MOTION FOR A THREE-DIMENSIONAL SUPERSONIC FLOW ARE SOLVED USING A NUMERICAL METHOD OF CHARACTERISTICS HAVING SECOND-ORDER ACCURACY. THE FLOW VARIABLES MUST BE SPECIFIED OVER A SPACE-LIKE INITIAL VALUE SURFACE WHICH ADJOINS THE NOZZLE BOUNDARIES. THE NOZZLE GEOMETRY IS SPECIFIED BY MEANS OF THE SUBROUTINE NALSUB. THE NOZZLE MAY HAVE PLANES OF SYMMETRY AND THE THERMODYNAMIC PROPERTIES OF THE GAS ARE DETERMINED BY MEANS OF THE SUBROUTINE ARDSUB.

## MAJOR ASSUMPTIONS

q17

THE GASDYNAMIC MODEL IS BASED ON THE FOLLOWING ASSUMPTIONS. 1. CONTINUUM, 2. INVISCID, 3. STEADY, 4. STRICTLY ADIABATIC, 5. FROZEN OR EQUILIBRIUM CHEMICAL COMPOSITION, AND 6. SPECIFIC INITIAL DATA AND BOUNDARIES.

## JOB TITLE

SAMPLE CASE NO. 3

## THERMODYNAMIC MODEL

A CALORICALLY AND THERMALLY PERFECT GAS IS SPECIFIED AND IS CHARACTERIZED BY THE FOLLOWING VALUES  
SPECIFIC HEAT RATIO = 1.40000 AND GAS CONSTANT = 53.30000 (FT-LBF/LBM-DEG R)

## FLOW GEOMETRY

NO PLANES OF SYMMETRY

Figure 8. Sample Case 3 Output

# NOZZLE GEOMETRY

## AXISYMMETRIC CIRCULAR-PARABOLA CONTOURED NOZZLE HAVING THE FOLLOWING PARAMETERS

### THROAT AND AXIS COORDINATES

XT = 0. (IN) YC = 1.0000 (IN) ZC = 1.0000 (IN)

### CONTOUR PARAMETERS

RT = 1.0000 (IN) RC = 1.0000 (IN) XE = 10.0000 (IN) RE = 4.0000

THETAT = 36.0000 (DEG) THETAE = 13.0000 (DEG)

## TYPE OF INITIAL DATA SURFACE

SOURCE FLOW IS USED TO ESTABLISH THE INITIAL VALUES. THE SOURCE ANGLE IS SPECIFIED & THE SOURCE POINT IS LOCATED ON THE NOZZLE AXIS SUCH THAT THE INITIAL FLOW IS TANGENT TO THE NOZZLE WALL. THE PROPERTIES OF THE SURFACE ARE ESTABLISHED BY SPECIFICATION OF THE PROPERTIES AT THE AXIAL POINT OF THE INITIAL VALUE SURFACE.

### SOURCE POINT

SOURCE ANGLE = 10.000 (DEG) X = -5.5838 (IN) Y = 1.0000 (IN) Z = 1.0000 (IN)

### REFERENCE POINT

X = 0.1736 (IN) Y = 1.0000 (IN) Z = 1.0000 (IN)

M = 1.5000 PT = 1000.00(LBF/IN\*\*2) H = 1255.0(F/10/100)

Figure 8. (Continued)

INITIAL DATA - X = 0.1736 (IN)

THRUST PARAMETERS

CROSS SECTION AREA = 3.2279 (IN<sup>2</sup>) MASS FLOW = 19.7158 (LPM/SEC)  
 XTHRUST = -3563.70 (LBF) YTHRUST = 0.00 (LBF) ZTHRUST = 0.00 (LBF)  
 XMOMT = 0.00 (FT-LBF) YMOMT = 3553.70 (FT-LBF) ZMOMT = 3563.70 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	X	Y	Z	M	Q	P	RHC	F	U	V	W	PI	H
1	1	1.7177	1.7177	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	554.8	554.8	1000.0	1255.0
1	2	1.8053	1.6179	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	627.5	477.7	1000.0	1255.0
1	3	1.8792	1.5076	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	679.6	392.4	1000.0	1255.0
1	4	1.9378	1.3885	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	724.9	300.3	1000.0	1255.0
1	5	1.9805	1.2627	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	757.9	202.1	1000.0	1255.0
1	6	2.0064	1.1375	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	778.0	102.4	1000.0	1255.0
1	7	2.0152	1.0000	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	784.8	0.0	1000.0	1255.0
1	8	2.0064	0.8675	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	778.0	-102.4	1000.0	1255.0
1	9	1.9805	0.7173	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	757.9	-202.1	1000.0	1255.0
1	10	1.9378	0.6115	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	724.9	-300.3	1000.0	1255.0
1	11	1.8792	0.4924	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	679.6	-392.4	1000.0	1255.0
1	12	1.8053	0.3621	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	627.5	-477.7	1000.0	1255.0
1	13	1.7177	0.2023	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	554.8	-554.8	1000.0	1255.0
2	1	1.6179	1.8053	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	477.7	554.8	1000.0	1255.0
2	2	1.6179	1.6179	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	476.2	476.2	1000.0	1255.0
2	3	1.6179	1.5137	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	476.2	386.4	1000.0	1255.0
2	4	1.7786	1.3967	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	600.8	306.1	1000.0	1255.0
2	5	1.8312	1.2701	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	641.4	206.4	1000.0	1255.0
2	6	1.8740	1.1367	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	666.0	105.5	1000.0	1255.0
2	7	1.8740	1.0000	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	674.4	0.0	1000.0	1255.0
2	8	1.8631	0.8633	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	666.0	-105.5	1000.0	1255.0
2	9	1.8312	0.7299	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	641.4	-206.4	1000.0	1255.0
2	10	1.7786	0.6033	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	600.8	-306.1	1000.0	1255.0
2	11	1.7071	0.4663	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	545.4	-396.4	1000.0	1255.0
2	12	1.6179	0.3021	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	476.2	-476.2	1000.0	1255.0
3	1	1.5076	1.8792	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	477.7	554.8	1000.0	1255.0
3	2	1.5137	1.7071	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	392.4	479.6	1000.0	1255.0
3	3	1.5075	1.5075	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	390.9	390.9	1000.0	1255.0
3	4	1.5968	1.3988	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	459.7	307.2	1000.0	1255.0
3	5	1.6631	1.2747	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	510.0	211.6	1000.0	1255.0
3	6	1.7040	1.1400	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	542.3	107.5	1000.0	1255.0
3	7	1.7174	1.0000	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	542.3	0.0	1000.0	1255.0
3	8	1.7040	0.8600	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	542.3	-107.5	1000.0	1255.0
3	9	1.6631	0.7253	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	510.0	-211.6	1000.0	1255.0
3	10	1.5968	0.6017	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	459.7	-307.2	1000.0	1255.0
3	11	1.5075	0.4975	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	390.9	-390.9	1000.0	1255.0
3	12	1.5147	0.2929	1.534	4493.8	4493.8	257.50	0.1950E 00	3552.8	4442.9	396.4	-479.6	1000.0	1255.0
3	13	1.5076	0.1208	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	392.4	-679.6	1000.0	1255.0
4	1	1.3885	1.9378	1.552	4519.2	4519.2	252.69	0.1932E 00	3533.7	4450.6	300.3	724.9	1000.0	1255.0
4	2	1.3967	1.7786	1.539	4493.7	4493.7	257.50	0.1950E 00	3552.8	4442.9	306.1	600.8	1000.0	1255.0
4	3	1.3988	1.5968	1.526	4469.3	4469.3	262.16	0.1983E 00	3571.1	4435.0	307.2	459.7	1000.0	1255.0
4	4	1.3884	1.3884	1.516	4447.7	4447.7	266.30	0.2006E 00	3587.1	4427.6	298.7	298.7	1000.0	1255.0
4	5	1.4758	1.2747	1.516	4447.7	4447.7	266.30	0.2006E 00	3587.1	4427.6	365.9	211.3	1000.0	1255.0

Figure 8. (Continued)

INITIAL DATA - X = 0.1736 (IN)

I	J	Y	Z	M	Q	P	RML	T	U	V	M	PT	H
		(IN)	(IN)	(FT/SEC)	(IN/142)	(IN/142)	(LB/FT <sup>3</sup> )	(DEG/M)	(/SEC)	(FT/SEC)	(FT/SEC)	(LB/FT <sup>2</sup> )	(LBM/LBM)
4	6	1.5306	1.1422	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	408.1	109.3	100C.0	1255.0
4	7	1.5494	1.0000	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	422.5	C.	100C.0	1255.0
4	8	1.5306	0.8578	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	408.1	-109.3	100C.0	1255.0
4	9	1.4758	0.7253	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	365.9	-211.1	100C.0	1255.0
4	10	1.3884	0.6116	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	298.7	-298.7	100C.0	1255.0
4	11	1.3808	0.5032	1.526	4469.3	262.16	0.1983E 00	3571.0	4435.0	307.2	-459.7	100C.0	1255.0
4	12	1.3867	0.2214	1.519	4493.1	257.50	0.1958E 00	3552.8	4442.9	306.1	-600.8	100C.0	1255.0
4	13	1.3885	0.0622	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	300.3	-774.9	100C.0	1255.0
5	1	1.2627	1.9805	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	203.1	751.5	100C.0	1255.0
5	2	1.2701	1.8312	1.539	4493.1	257.50	0.1958E 00	3552.8	4442.9	208.4	641.4	100C.0	1255.0
5	3	1.2747	1.6631	1.526	4469.3	262.16	0.1983E 00	3571.0	4435.0	211.6	510.8	100C.0	1255.0
5	4	1.2747	1.4758	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	211.3	365.5	100C.0	1255.0
5	5	1.2627	1.2627	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	201.8	201.8	100C.0	1255.0
5	6	1.3433	1.1422	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	263.6	109.7	100C.0	1255.0
5	7	1.3716	1.0000	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	265.4	C.	100C.0	1255.0
5	8	1.3433	0.8578	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	263.6	-109.7	100C.0	1255.0
5	9	1.2627	0.7253	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	261.8	-261.8	100C.0	1255.0
5	10	1.2747	0.5032	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	211.3	-365.5	100C.0	1255.0
5	11	1.2747	0.2214	1.526	4469.3	262.16	0.1983E 00	3571.0	4435.0	211.6	-510.8	100C.0	1255.0
5	12	1.2701	0.0622	1.552	4493.1	257.50	0.1958E 00	3552.8	4442.9	208.4	-774.9	100C.0	1255.0
5	13	1.2627	0.0000	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	201.1	-751.5	100C.0	1255.0
6	1	1.1325	2.0064	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	107.4	778.7	100C.0	1255.0
6	2	1.1367	1.8631	1.539	4493.1	257.50	0.1958E 00	3552.8	4442.9	105.5	666.7	100C.0	1255.0
6	3	1.1400	1.7040	1.526	4469.3	262.16	0.1983E 00	3571.0	4435.0	107.9	542.3	100C.0	1255.0
6	4	1.1422	1.5306	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	109.2	408.1	100C.0	1255.0
6	5	1.1422	1.3433	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	109.2	263.6	100C.0	1255.0
6	6	1.1325	1.1325	1.507	4419.9	271.68	0.2035E 00	3607.6	4417.6	101.7	101.7	100C.0	1255.0
6	7	1.1874	1.0000	1.502	4419.9	271.68	0.2035E 00	3607.6	4417.6	143.8	C.	100C.0	1255.0
6	8	1.1325	0.8675	1.502	4419.9	271.68	0.2035E 00	3607.6	4417.6	101.7	-101.7	100C.0	1255.0
6	9	1.1422	0.6567	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	109.2	-263.6	100C.0	1255.0
6	10	1.1422	0.4594	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	109.2	-408.1	100C.0	1255.0
6	11	1.1400	0.2760	1.526	4469.3	262.16	0.1983E 00	3571.0	4435.0	107.9	-542.3	100C.0	1255.0
6	12	1.1367	0.1369	1.539	4493.1	257.50	0.1958E 00	3552.8	4442.9	107.4	-778.7	100C.0	1255.0
6	13	1.1325	-0.0064	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	0.0	-784.9	100C.0	1255.0
7	1	1.0000	2.7152	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	0.0	784.9	100C.0	1255.0
7	2	1.0000	1.7178	1.539	4493.1	257.50	0.1958E 00	3552.8	4442.9	0.0	674.4	100C.0	1255.0
7	3	1.0000	1.5494	1.526	4469.3	262.16	0.1983E 00	3571.0	4435.0	0.0	551.0	100C.0	1255.0
7	4	1.0000	1.3433	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	0.0	422.5	100C.0	1255.0
7	5	1.0000	1.1716	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	0.0	283.4	100C.0	1255.0
7	6	1.0000	1.0000	1.507	4419.9	271.68	0.2035E 00	3607.6	4417.6	0.0	143.8	100C.0	1255.0
7	7	1.0000	0.8126	1.502	4419.9	271.68	0.2035E 00	3610.4	4417.6	0.0	C.	100C.0	1255.0
7	8	1.0000	0.6284	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	-0.0	-143.8	100C.0	1255.0
7	9	1.0000	0.4506	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	-0.0	-283.4	100C.0	1255.0
7	10	1.0000	0.2782	1.526	4469.3	262.16	0.1983E 00	3571.0	4435.0	-0.0	-422.5	100C.0	1255.0
7	11	1.0000	0.1260	1.539	4493.1	257.50	0.1958E 00	3552.8	4442.9	-0.0	-551.0	100C.0	1255.0
7	12	1.0000	-0.0157	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-0.0	-774.9	100C.0	1255.0
8	1	0.8675	2.0064	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-102.4	778.7	100C.0	1255.0
8	2	0.8631	1.8631	1.539	4493.1	257.50	0.1958E 00	3552.8	4442.9	-105.5	666.7	100C.0	1255.0
8	3	0.8600	1.7040	1.526	4469.3	262.16	0.1983E 00	3571.0	4435.0	-107.9	542.3	100C.0	1255.0
8	4	0.8578	1.5306	1.516	4447.7	266.30	0.2006E 00	3587.1	4427.6	-109.2	408.1	100C.0	1255.0
8	5	0.8578	1.3433	1.507	4430.8	269.58	0.2023E 00	3599.6	4421.6	-109.2	263.6	100C.0	1255.0
8	6	0.8675	1.1325	1.502	4419.9	271.68	0.2035E 00	3607.6	4417.6	-101.7	101.7	100C.0	1255.0
8	7	0.8126	1.0000	1.502	4419.9	271.68	0.2035E 00	3607.6	4417.6	-143.8	0.0	100C.0	1255.0

Figure 8. (Continued)

INITIAL DATA														X = 0.1736 (IM)													
I	J	Y	Z	M	C	P	RMC	I	U	V	W	PT	H														
(IN)	(IN)				(FT/SEC)	(IN/IN2)	(LBP/13)	(G/G)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBP/IN2)	(BTU/LBM)														
8	8	0.9675	0.8675	1.502	4419.9	271.68	0.20351 00	3607.6	4417.6	-101.7	-101.7	1000.0	1255.0														
8	9	0.8578	0.5467	1.507	4430.8	269.58	0.20351 00	3599.6	4421.6	-104.7	-263.6	1000.0	1255.0														
8	10	0.8573	0.5494	1.512	4430.8	269.58	0.20351 00	3587.1	4427.6	-109.3	-408.1	1000.0	1255.0														
8	11	0.8600	0.2760	1.526	4459.3	262.16	0.19831 00	3571.1	4435.0	-107.9	-542.2	1000.0	1255.0														
8	12	0.8633	0.1369	1.535	4493.7	251.50	0.19581 00	3552.8	4442.9	-105.5	-666.6	1000.0	1255.0														
8	13	0.8675	0.0506	1.552	4519.2	252.69	0.19321 00	3533.7	4450.6	-105.4	-778.0	1000.0	1255.0														
9	1	0.8713	1.9805	1.552	4519.2	252.69	0.19321 00	3552.8	4450.6	-208.1	757.5	1000.0	1255.0														
9	2	0.7299	1.8312	1.539	4491.8	257.50	0.19581 00	3552.8	4442.9	-208.4	641.4	1000.0	1255.0														
9	3	0.7253	1.6631	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-211.6	510.8	1000.0	1255.0														
9	4	0.7253	1.4758	1.516	4447.7	266.30	0.20061 00	3587.1	4427.6	-211.3	365.9	1000.0	1255.0														
9	5	0.7373	1.2727	1.507	4430.8	269.58	0.20231 00	3599.6	4421.6	-201.8	201.8	1000.0	1255.0														
9	6	0.6567	1.1427	1.507	4430.8	269.58	0.20231 00	3599.6	4421.6	-263.6	109.2	1000.0	1255.0														
9	7	0.6284	1.0000	1.507	4430.8	269.58	0.20231 00	3599.6	4421.6	-263.6	0.0	1000.0	1255.0														
9	8	0.6567	0.8578	1.507	4430.8	269.58	0.20231 00	3599.6	4421.6	-263.6	-104.2	1000.0	1255.0														
9	9	0.7373	0.7373	1.507	4430.8	269.58	0.20231 00	3599.6	4421.6	-201.8	-201.8	1000.0	1255.0														
9	10	0.7253	0.5242	1.515	4447.7	266.30	0.20061 00	3587.1	4427.6	-211.3	-365.5	1000.0	1255.0														
9	11	0.7253	0.3369	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-211.6	-510.8	1000.0	1255.0														
9	12	0.7299	0.1688	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-208.4	-641.4	1000.0	1255.0														
9	13	0.7373	0.0195	1.552	4519.2	252.69	0.19321 00	3533.7	4450.6	-306.3	724.5	1000.0	1255.0														
10	1	0.6115	1.9378	1.552	4519.2	252.69	0.19321 00	3533.7	4450.6	-306.3	724.5	1000.0	1255.0														
10	2	0.6033	1.7786	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-306.1	600.8	1000.0	1255.0														
10	3	0.6012	1.5968	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-301.2	454.7	1000.0	1255.0														
10	4	0.6012	1.3884	1.516	4447.7	266.30	0.20061 00	3587.1	4427.6	-304.7	298.7	1000.0	1255.0														
10	5	0.5242	1.2747	1.516	4447.7	266.30	0.20061 00	3587.1	4427.6	-305.9	211.3	1000.0	1255.0														
10	6	0.5242	1.1422	1.516	4447.7	266.30	0.20061 00	3587.1	4427.6	-408.1	104.3	1000.0	1255.0														
10	7	0.4506	1.0000	1.516	4447.7	266.30	0.20061 00	3587.1	4427.6	-422.5	0.0	1000.0	1255.0														
10	8	0.4506	0.8578	1.516	4447.7	266.30	0.20061 00	3587.1	4427.6	-408.1	-109.3	1000.0	1255.0														
10	9	0.5242	0.7253	1.516	4447.7	266.30	0.20061 00	3587.1	4427.6	-365.9	-211.3	1000.0	1255.0														
10	10	0.6012	0.6116	1.516	4447.7	266.30	0.20061 00	3587.1	4427.6	-394.7	-298.7	1000.0	1255.0														
10	11	0.6012	0.4032	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-307.2	-459.7	1000.0	1255.0														
10	12	0.6012	0.2214	1.535	4493.7	257.50	0.19581 00	3552.8	4442.9	-306.1	-600.8	1000.0	1255.0														
10	13	0.6115	0.0622	1.552	4519.2	252.69	0.19321 00	3533.7	4450.6	-300.3	-724.5	1000.0	1255.0														
11	1	0.4924	1.8774	1.552	4519.2	252.69	0.19321 00	3533.7	4450.6	-392.4	679.6	1000.0	1255.0														
11	2	0.4813	1.7071	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-390.9	545.6	1000.0	1255.0														
11	3	0.4924	1.5075	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-390.9	390.9	1000.0	1255.0														
11	4	0.4032	1.3198	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-459.7	307.2	1000.0	1255.0														
11	5	0.3369	1.2747	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-510.8	211.6	1000.0	1255.0														
11	6	0.2960	1.1400	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-542.3	107.9	1000.0	1255.0														
11	7	0.2822	1.0000	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-553.0	0.0	1000.0	1255.0														
11	8	0.2960	0.8600	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-542.3	-107.9	1000.0	1255.0														
11	9	0.3369	0.7253	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-510.8	-211.6	1000.0	1255.0														
11	10	0.4032	0.6012	1.526	4469.3	262.16	0.19831 00	3571.1	4435.0	-459.7	-307.2	1000.0	1255.0														
11	11	0.4924	0.4924	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-390.9	-545.6	1000.0	1255.0														
11	12	0.4924	0.2799	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-394.7	-679.6	1000.0	1255.0														
11	13	0.4924	0.1208	1.552	4519.2	252.69	0.19321 00	3533.7	4450.6	-397.4	-778.0	1000.0	1255.0														
12	1	0.3821	1.8053	1.552	4519.2	252.69	0.19321 00	3533.7	4450.6	-474.8	622.5	1000.0	1255.0														
12	2	0.3821	1.6179	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-474.8	474.8	1000.0	1255.0														
12	3	0.2229	1.5117	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-396.6	396.6	1000.0	1255.0														
12	4	0.2214	1.3967	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-600.8	306.1	1000.0	1255.0														
12	5	0.1638	1.2701	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-641.4	208.4	1000.0	1255.0														
12	6	0.1369	1.1467	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-684.0	105.5	1000.0	1255.0														
12	7	0.1260	1.0000	1.519	4493.7	257.50	0.19581 00	3552.8	4442.9	-674.4	0.0	1000.0	1255.0														
12	8	0.1260	0.8633	1.535	4493.7	257.50	0.19581 00	3552.8	4442.9	-684.0	-105.5	1000.0	1255.0														
12	9	0.1688	0.7299	1.539	4493.7	257.50	0.19581 00	3552.8	4442.9	-641.4	-208.4	1000.0	1255.0														

Figure 8. (Continued)

INITIAL DATA -				X = 0.1736 (IN)														
I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHO (LBM/FT3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	P1 (LBF/IN2)	H (BTU/LB-H)					
12	10	0.2214	0.6033	1.539	4493.7	257.50	0.1958E 00	3552.8	4442.9	-600.8	-306.1	1000.0	1255.0					
12	11	0.2929	0.4863	1.539	4493.8	257.50	0.1958E 00	3552.8	4442.9	-565.8	-396.4	1000.0	1255.0					
12	12	0.3821	0.3821	1.539	4493.7	257.50	0.1958E 00	3552.8	4442.9	-476.8	-476.8	1000.0	1255.0					
12	13	0.3821	0.1947	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-477.7	-622.5	1000.0	1255.0					
13	1	0.2823	1.7177	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-554.8	554.8	1000.0	1255.0					
13	2	0.1947	1.6179	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-622.5	477.7	1000.0	1255.0					
13	3	0.1208	1.5076	1.552	4519.2	252.68	0.1932E 00	3533.7	4450.6	-679.6	392.4	1000.0	1255.0					
13	4	0.0622	1.3985	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-724.9	300.2	1000.0	1255.0					
13	5	0.0195	1.2627	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-757.9	203.1	1000.0	1255.0					
13	6	-0.0064	1.1325	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-776.0	102.4	1000.0	1255.0					
13	7	-0.0152	1.0000	1.552	4519.2	252.68	0.1932E 00	3533.7	4450.6	-776.0	0.0	1000.0	1255.0					
13	8	-0.0064	0.8675	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-776.0	-102.4	1000.0	1255.0					
13	9	0.0145	0.7373	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-757.9	-203.1	1000.0	1255.0					
13	10	0.0622	0.6115	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-724.9	-300.2	1000.0	1255.0					
13	11	0.1208	0.4924	1.552	4519.2	252.68	0.1932E 00	3533.7	4450.6	-679.6	-392.4	1000.0	1255.0					
13	12	0.1947	0.3821	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-622.5	-477.7	1000.0	1255.0					
13	13	0.2823	0.2823	1.552	4519.2	252.69	0.1932E 00	3533.7	4450.6	-554.8	-554.8	1000.0	1255.0					
XSTEP REGULATION PARAMETERS																		
LIMITING POINT		I = 1	AND J = 4	SAFETY FACTOR =		0.64000		DELTA X =		0.0832								

XSTEP REGULATION PARAMETERS

LIMITING POINT I = 1 AND J = 4 SAFETY FACTOR = 0.64000 DELTA X = 0.0832

Figure 8. (Continued)

SOLUTION SURFACE - X = 10.0000 (IN) PLANE 18

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA= 50.1220 (IN\*\*2) MASS FLOW RATE RATIO = 0.98511

XTHRUST = -4464.86 (LBF) YTHRUST = 0.00 (LBF) ZTHRUST = -0.00 (LBF)

XMOM = 0.05 (FT-LBF) YMOM = 4532.24 (FT-LBF) ZMOM = 4532.35 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y (IN)	Z (IN)	H	Q (FT/SEC)	P (LBF/IN2)	RHO (LBM/FT3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN2)	H (BTU/LBM)
1	1	3.8306	3.8262	4.406	7069.0	3.89	0.9797E-02	1072.2	6887.9	1123.6	1123.2	1000.0	1255.0
1	2	4.1732	3.8353	4.407	7059.4	3.88	0.9798E-02	1071.8	6888.2	1262.3	967.3	1000.0	1255.0
1	3	4.4601	3.5069	4.411	7070.5	3.87	0.9757E-02	1070.5	6888.5	1373.8	801.5	1000.0	1255.0
1	4	4.6894	2.5454	4.413	7071.2	3.86	0.9740E-02	1069.7	6889.9	1462.5	625.6	1000.0	1255.0
1	5	4.8597	2.0499	4.415	7071.9	3.85	0.9721E-02	1068.9	6890.6	1530.7	433.5	1000.0	1255.0
1	6	4.9647	1.5300	4.414	7071.7	3.85	0.9725E-02	1069.1	6890.4	1575.2	222.7	1000.0	1255.0
1	7	5.0000	1.0307	4.414	7071.5	3.85	0.9730E-02	1069.2	6890.3	1590.7	0.8	1000.0	1255.0
1	8	4.9652	0.4732	4.414	7071.6	3.85	0.9729E-02	1069.2	6890.3	1575.3	-221.2	1000.0	1255.0
1	9	4.8603	-0.0478	4.414	7071.6	3.85	0.9728E-02	1069.1	6890.4	1530.9	-432.6	1000.0	1255.0
1	10	4.6894	-0.5455	4.412	7070.9	3.86	0.9748E-02	1070.0	6889.6	1462.4	-625.8	1000.0	1255.0
1	11	4.4587	-1.0094	4.410	7070.2	3.87	0.9766E-02	1070.8	6889.0	1372.9	-802.9	1000.0	1255.0
1	12	4.1699	-1.4396	4.406	7069.2	3.89	0.9793E-02	1072.0	6888.0	1260.4	-969.6	1000.0	1255.0
1	13	3.8258	-1.8111	4.406	7069.0	3.89	0.9797E-02	1072.2	6887.8	1123.0	-1125.5	1000.0	1255.0
2	1	3.4396	4.1699	4.406	7069.2	3.89	0.9793E-02	1072.0	6888.0	969.7	1260.4	1000.0	1255.0
2	2	3.5050	3.4999	4.440	7080.1	3.73	0.9502E-02	1059.2	6951.5	949.2	949.2	1000.0	1255.0
2	3	3.8578	3.0754	4.442	7080.7	3.72	0.9446E-02	1058.4	6953.7	1078.1	787.7	1000.0	1255.0
2	4	4.1456	2.5981	4.447	7082.2	3.69	0.9446E-02	1056.6	6955.3	1186.8	610.8	1000.0	1255.0
2	5	4.3595	2.0942	4.448	7082.7	3.69	0.9434E-02	1056.1	6955.3	1269.3	420.4	1000.0	1255.0
2	6	4.4918	1.5559	4.447	7082.4	3.69	0.9440E-02	1056.4	6954.5	1321.0	213.4	1000.0	1255.0
2	7	4.5408	1.0339	4.444	7081.5	3.70	0.9464E-02	1057.5	6952.8	1344.2	0.0	1000.0	1255.0
2	8	4.4927	0.4499	4.447	7082.3	3.69	0.9445E-02	1056.6	6954.3	1323.5	-211.5	1000.0	1255.0
2	9	4.3614	-0.0927	4.447	7082.4	3.69	0.9442E-02	1056.5	6954.8	1270.8	-420.2	1000.0	1255.0
2	10	4.1466	-0.5010	4.446	7081.9	3.70	0.9454E-02	1057.0	6954.6	1188.1	-612.4	1000.0	1255.0
2	11	3.8556	-1.0812	4.441	7080.5	3.72	0.9493E-02	1058.7	6953.2	1078.1	-790.0	1000.0	1255.0
2	12	3.4996	-1.5052	4.440	7080.1	3.73	0.9502E-02	1059.2	6951.5	949.0	-950.5	1000.0	1255.0
2	13	3.4345	-2.1739	4.407	7069.4	3.88	0.9788E-02	1071.8	6888.2	966.8	-1762.6	1000.0	1255.0
3	1	3.0095	4.4586	4.410	7070.2	3.87	0.9766E-02	1070.8	6889.0	803.0	1372.8	1000.0	1255.0
3	2	3.0806	3.8556	4.411	7080.5	3.72	0.9492E-02	1058.7	6953.2	789.6	1078.1	1000.0	1255.0
3	3	3.1370	3.1355	4.494	7091.3	3.48	0.9053E-02	1038.9	7019.4	740.9	741.7	1000.0	1255.0
3	4	3.5069	2.6664	4.495	7097.6	3.48	0.9045E-02	1038.5	7021.8	853.2	584.6	1000.0	1255.0
3	5	3.7853	2.1418	4.497	7098.3	3.47	0.9026E-02	1037.6	7022.0	950.8	403.4	1000.0	1255.0
3	6	3.9350	1.5871	4.496	7097.9	3.47	0.9038E-02	1038.2	7020.7	1023.4	204.6	1000.0	1255.0
3	7	4.0195	1.0012	4.490	7095.9	3.50	0.9089E-02	1040.5	7017.9	1048.9	-0.4	1000.0	1255.0
3	8	3.9563	0.4140	4.495	7097.7	3.48	0.9043E-02	1038.4	7020.3	1024.6	-205.5	1000.0	1255.0
3	9	3.7872	-0.1333	4.496	7098.0	3.47	0.9034E-02	1038.0	7021.3	958.9	-404.8	1000.0	1255.0
3	10	3.5077	-0.6691	4.494	7097.3	3.48	0.9053E-02	1038.8	7021.2	855.1	-585.5	1000.0	1255.0
3	11	3.1353	-1.1369	4.494	7097.3	3.48	0.9053E-02	1038.9	7019.5	741.4	-740.5	1000.0	1255.0
3	12	3.0754	-1.8581	4.442	7080.7	3.72	0.9486E-02	1058.5	6953.6	787.4	-1078.4	1000.0	1255.0
3	13	3.0060	-2.4607	4.410	7070.5	3.87	0.9758E-02	1070.5	6889.3	801.1	-1374.1	1000.0	1255.0
4	1	2.5453	4.6895	4.411	7070.8	3.86	0.9749E-02	1070.1	6889.6	625.6	1462.4	1000.0	1255.0
4	2	2.6010	4.1472	4.445	7081.9	3.70	0.9455E-02	1057.1	6954.5	614.4	1188.6	1000.0	1255.0
4	3	2.6687	3.5078	4.494	7097.3	3.48	0.9053E-02	1038.8	7021.2	585.2	355.3	1000.0	1255.0
4	4	2.7503	2.7506	4.587	7125.8	3.10	0.8336E-02	1005.1	7086.9	524.7	524.7	1000.0	1255.0
4	5	3.1403	2.2219	4.582	7124.2	3.12	0.8375E-02	1007.0	7087.1	629.7	361.2	1000.0	1255.0

Figure 8. (Continued)

SOLUTION SURFACE - X = 10.0000 (IN) PLANE 18													
I	J	Y	Z	M	Q	P	RHO	T	U	V	N	PT	H
		(IN)	(IN)		(FT/SEC)	(LBF/IN <sup>2</sup> )	(LBF/FT <sup>3</sup> )	(DEG R)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN <sup>2</sup> )	(BTU/LB/MI)
4	6	3.3825	1.6388	4.580	7123.7	3.13	0.8387E-02	1007.6	7085.5	716.6	171.5	1C0C.0	1255.0
4	7	3.4701	0.9999	4.573	7121.5	3.16	0.8442E-02	1010.2	7082.7	742.3	-1.1	1C0C.0	1255.0
4	9	3.3842	0.3606	4.579	7123.5	3.13	0.8393E-02	1007.8	7085.0	718.4	-173.4	1C0C.0	1255.0
4	9	3.1422	-0.2229	4.581	7123.9	3.12	0.8381E-02	1007.3	7086.6	632.2	-361.5	1C0C.0	1255.0
4	10	2.7505	-0.7500	4.587	7125.8	3.10	0.8336E-02	1005.1	7086.9	526.2	-524.5	1C0C.0	1255.0
4	11	2.6665	-1.5068	4.495	7097.5	3.48	0.9046E-02	1038.5	7021.8	584.5	-853.2	1C0C.0	1255.0
4	12	2.5980	-2.1456	4.447	7082.2	3.69	0.9446E-02	1056.6	6955.3	610.6	-1186.9	1C0C.0	1255.0
4	13	2.5449	-2.6896	4.412	7071.1	3.86	0.9741E-02	1069.7	6889.9	625.4	-1467.6	1C0C.0	1255.0
5	1	2.0469	4.8606	4.414	7071.6	3.85	0.9729E-02	1069.2	6890.3	432.0	1531.1	1C0C.0	1255.0
5	2	2.0927	4.3621	4.447	7082.4	3.69	0.9442E-02	1056.5	6954.6	420.3	1271.3	1C0C.0	1255.0
5	3	2.1432	3.7876	4.496	7098.0	3.47	0.9034E-02	1038.0	7021.2	404.8	959.2	1C0C.0	1255.0
5	4	2.2229	3.1422	4.581	7123.9	3.12	0.8381E-02	1007.3	7086.6	361.5	632.4	1C0C.0	1255.0
5	5	2.2993	2.2999	4.842	7197.0	2.28	0.6885E-02	920.2	7178.3	365.0	366.5	1C0C.0	1255.0
5	6	2.7039	1.6774	4.829	7193.4	2.31	0.6762E-02	924.4	7175.4	477.8	175.4	1C0C.0	1255.0
5	7	2.8405	0.9997	4.822	7191.7	2.33	0.6800E-02	926.5	7173.0	517.5	-0.9	1C0C.0	1255.0
5	8	2.7050	0.3221	4.828	7193.3	2.32	0.6766E-02	924.6	7175.1	473.3	-176.6	1C0C.0	1255.0
5	9	2.2998	-0.2990	4.842	7197.0	2.28	0.6884E-02	920.1	7178.4	364.3	-364.5	1C0C.0	1255.0
5	10	2.2221	-1.1400	4.587	7124.2	3.12	0.8375E-02	1007.0	7087.1	361.1	-629.5	1C0C.0	1255.0
5	11	2.1418	-1.7849	4.497	7098.3	3.47	0.9026E-02	1037.6	7022.0	403.2	-956.5	1C0C.0	1255.0
5	12	2.0940	-2.3590	4.448	7082.7	3.69	0.9434E-02	1056.1	6951.4	426.2	-1269.0	1C0C.0	1255.0
5	13	2.0501	-2.8597	4.415	7071.8	3.85	0.9722E-02	1068.9	6890.6	433.7	-1530.6	1C0C.0	1255.0
6	1	1.5251	4.9654	4.414	7071.5	3.85	0.9730E-02	1069.2	6890.3	220.2	1575.5	1C0C.0	1255.0
6	2	1.5502	4.4933	4.447	7082.3	3.69	0.9445E-02	1056.6	6954.2	211.6	1323.9	1C0C.0	1255.0
6	3	1.5862	3.9566	4.495	7097.6	3.48	0.9044E-02	1038.4	7020.2	205.7	1024.9	1C0C.0	1255.0
6	4	1.6396	3.3843	4.579	7123.5	3.13	0.8393E-02	1007.8	7085.0	173.5	718.6	1C0C.0	1255.0
6	5	1.6781	2.7051	4.828	7123.7	3.13	0.8388E-02	1007.6	7085.5	171.7	-716.3	1C0C.0	1255.0
6	6	1.7124	1.7125	5.258	7295.1	2.32	0.6766E-02	924.6	7175.1	176.1	479.4	1C0C.0	1255.0
6	7	2.0066	1.0001	5.254	7294.2	1.41	0.4737E-02	801.7	7285.4	265.1	265.5	1C0C.0	1255.0
6	8	1.7125	0.2880	5.258	7295.1	1.41	0.4752E-02	802.7	7284.7	372.8	-0.1	1C0C.0	1255.0
6	9	1.6774	-0.7036	4.829	7193.4	2.31	0.6762E-02	924.4	7175.4	175.2	-677.7	1C0C.0	1255.0
6	10	1.6388	-1.3821	4.580	7123.7	3.13	0.8388E-02	1007.6	7085.5	171.7	-716.3	1C0C.0	1255.0
6	11	1.5870	-1.9544	4.496	7097.9	3.47	0.9038E-02	1038.2	7020.8	204.4	-1023.0	1C0C.0	1255.0
6	12	1.5558	-2.4911	4.447	7082.4	3.69	0.9440E-02	1056.4	6954.4	213.2	-1322.5	1C0C.0	1255.0
6	13	1.5310	-2.9665	4.414	7071.7	3.85	0.9726E-02	1069.1	6890.3	223.3	-1375.1	1C0C.0	1255.0
7	1	0.9963	5.0000	4.414	7071.6	3.85	0.9729E-02	1069.2	6890.3	-2.0	1590.2	1C0C.0	1255.0
7	2	0.9961	4.5408	4.444	7081.6	3.85	0.9442E-02	1056.5	6952.8	-1.2	1344.2	1C0C.0	1255.0
7	3	0.9991	4.0196	4.490	7055.9	3.50	0.9089E-02	1040.5	7017.9	-0.6	1049.0	1C0C.0	1255.0
7	4	1.0004	3.4703	4.573	7121.5	3.16	0.8442E-02	1010.2	7082.7	1.4	742.5	1C0C.0	1255.0
7	5	1.0006	2.8406	4.822	7191.7	2.33	0.6801E-02	926.5	7177.0	1.1	517.6	1C0C.0	1255.0
7	6	1.0003	2.0667	5.254	7294.2	1.41	0.4752E-02	802.7	7284.7	0.3	372.8	1C0C.0	1255.0
7	7	1.0000	1.0002	5.461	7336.0	1.12	0.4033E-02	751.8	7336.0	0.0	0.1	1C0C.0	1255.0
7	8	1.0001	-0.3063	5.255	7294.3	1.41	0.4751E-02	802.7	7284.8	-0.2	-372.7	1C0C.0	1255.0
7	9	0.9996	-0.8404	4.822	7191.7	2.33	0.6800E-02	926.5	7173.1	-1.0	-517.4	1C0C.0	1255.0
7	10	0.9998	-1.4701	4.573	7121.5	3.16	0.8442E-02	1010.2	7082.7	-1.2	-742.3	1C0C.0	1255.0
7	11	1.0012	2.0195	4.489	7055.9	3.50	0.9090E-02	1040.5	7017.9	-0.4	-1048.9	1C0C.0	1255.0
7	12	1.0039	-2.5408	4.444	7081.5	3.70	0.9465E-02	1057.5	6952.7	1.3	-1344.3	1C0C.0	1255.0
8	1	0.0028	-3.0000	4.414	7071.5	3.85	0.9730E-02	1069.3	6890.3	1.4	-1590.7	1C0C.0	1255.0
8	2	0.4685	4.9645	4.414	7071.7	3.85	0.9726E-02	1069.1	6890.4	1.4	1575.0	1C0C.0	1255.0
8	3	0.4131	3.9545	4.447	7082.5	3.69	0.9440E-02	1056.4	6954.6	-213.3	1322.5	1C0C.0	1255.0
8	4	0.3228	2.7060	4.829	7123.7	3.13	0.8388E-02	1007.6	7085.5	-171.7	716.5	1C0C.0	1255.0
8	5	0.2879	1.7124	5.258	7295.1	2.31	0.6763E-02	924.4	7175.4	-175.2	477.8	1C0C.0	1255.0
8	6	0.2878	1.7124	5.258	7295.1	2.31	0.6763E-02	924.4	7175.4	-175.2	477.8	1C0C.0	1255.0
8	7	-0.0062	1.0003	5.255	7294.3	1.41	0.4751E-02	802.7	7284.8	-265.1	265.2	1C0C.0	1255.0

Figure 8. (Continued)

SOLUTION SURFACE -														X F		10.0000		(IN)		PLANE 18															
I	J	Y	Z	M	Q	P	RHU	T	U	V	W	PI	H																						
		(IN)	(IN)		(FT/SEC)	(LB/FT/IN <sup>2</sup> )	(LB/FT/IN <sup>2</sup> )	(DEG K)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LB/FT/IN <sup>2</sup> )	(BTU/LB/IN)																						
8	8	0.2880	0.2879	5.258	7295.1	1.41	0.4736E-02	601.7	7235.5	-265.1	-265.2	1000.0	1255.0																						
8	9	0.3721	-0.7049	4.828	7193.3	2.31	0.6765E-02	924.6	7175.2	-176.0	-479.2	1000.0	1255.0																						
8	10	0.3605	-1.1842	4.579	7123.4	3.13	0.8393E-02	1007.9	7085.0	-173.3	-718.4	1000.0	1255.0																						
8	11	0.6151	-1.9565	4.495	7097.6	3.48	0.9044E-02	1038.4	7050.3	-205.5	-1024.7	1000.0	1255.0																						
8	12	0.4500	-2.4929	4.447	7082.2	3.69	0.9445E-02	1056.6	6954.2	-211.4	-1323.7	1000.0	1255.0																						
8	13	0.4739	-2.7652	4.414	7071.5	3.85	0.9730E-02	1069.3	6890.3	-220.9	-175.4	1000.0	1255.0																						
9	1	-0.0504	4.8596	4.415	7011.8	3.85	0.9722E-02	1068.9	6890.6	-433.8	1530.6	1000.0	1255.0																						
9	2	-0.0941	4.3589	4.448	7082.7	3.69	0.9433E-02	1056.1	6955.4	-420.3	1268.5	1000.0	1255.0																						
9	3	-0.1419	3.7851	4.597	7098.3	3.47	0.9026E-02	1037.5	7022.0	-403.3	956.5	1000.0	1255.0																						
9	4	-0.2220	3.1404	4.582	7124.2	3.12	0.8375E-02	1007.0	7087.1	-361.2	629.7	1000.0	1255.0																						
9	5	-0.2995	2.2993	4.842	7197.0	2.28	0.6684E-02	920.1	7178.4	-364.3	364.5	1000.0	1255.0																						
9	6	-0.7048	1.6782	4.828	7193.3	2.32	0.6765E-02	924.6	7175.1	-479.2	176.1	1000.0	1255.0																						
9	7	-0.8404	1.3007	4.822	7191.7	2.33	0.6800E-02	926.5	7173.1	-517.4	1.1	1000.0	1255.0																						
9	8	-0.7037	0.3229	4.829	7193.4	2.31	0.6761E-02	924.4	7175.4	-477.7	-175.1	1000.0	1255.0																						
9	9	-0.2990	-0.2495	4.842	7197.0	2.44	0.6683E-02	920.1	7178.4	-364.8	-366.2	1000.0	1255.0																						
9	10	-0.2229	-1.1421	4.581	7123.9	3.12	0.8381E-02	1007.3	7086.6	-361.4	-632.1	1000.0	1255.0																						
9	11	-0.1430	-1.7873	4.596	7098.0	3.47	0.9034E-02	1038.0	7021.3	-404.6	-958.9	1000.0	1255.0																						
9	12	-0.0925	-2.3614	4.447	7082.4	3.69	0.9442E-02	1056.5	6954.8	-420.1	-1270.8	1000.0	1255.0																						
9	13	-0.0475	-2.8604	4.414	7071.6	3.85	0.9728E-02	1069.2	6890.3	-432.5	-1530.5	1000.0	1255.0																						
10	1	-0.5451	4.6895	4.412	7071.1	3.86	0.9740E-02	1069.7	6889.9	-425.5	1482.6	1000.0	1255.0																						
10	2	-0.5903	4.1457	4.447	7082.2	3.69	0.9446E-02	1056.7	6954.3	-610.9	1186.8	1000.0	1255.0																						
10	3	-0.6666	3.5071	4.495	7097.6	3.48	0.9046E-02	1038.5	7021.8	-584.7	853.2	1000.0	1255.0																						
10	4	-0.7503	2.7503	4.587	7125.8	3.10	0.8335E-02	1005.1	7086.6	-632.1	361.5	1000.0	1255.0																						
10	5	-1.1420	2.2231	4.581	7123.9	3.12	0.8381E-02	1007.3	7085.0	-718.4	173.4	1000.0	1255.0																						
10	6	-1.3441	1.6497	4.579	7121.5	3.16	0.8442E-02	1010.2	7082.7	-742.3	1.3	1000.0	1255.0																						
10	7	-1.4701	0.3004	4.573	7121.5	3.13	0.8393E-02	1007.9	7085.0	-718.4	173.4	1000.0	1255.0																						
10	8	-1.3822	0.3614	4.580	7123.7	3.13	0.8387E-02	1007.6	7085.5	-716.3	-171.6	1000.0	1255.0																						
10	9	-1.1401	-0.2219	4.582	7124.2	3.12	0.8375E-02	1007.0	7087.1	-629.5	-361.1	1000.0	1255.0																						
10	10	-0.7500	-0.7503	4.587	7125.8	3.10	0.8335E-02	1005.1	7087.0	-524.4	-526.1	1000.0	1255.0																						
10	11	-0.6630	-1.5077	4.494	7097.3	3.48	0.9052E-02	1038.8	7021.3	-585.3	-855.1	1000.0	1255.0																						
10	12	-0.6007	-2.1465	4.446	7081.9	3.70	0.9455E-02	1057.0	6954.6	-612.1	-1188.1	1000.0	1255.0																						
10	13	-0.5452	-2.6895	4.412	7070.9	3.86	0.9748E-02	1070.0	6889.6	-625.6	-1482.4	1000.0	1255.0																						
11	1	-1.0062	4.4605	4.410	7070.5	3.87	0.9758E-02	1070.5	6889.3	-630.2	1374.0	1000.0	1255.0																						
11	2	-1.0758	3.8582	4.442	7080.7	3.72	0.9486E-02	1058.5	6953.6	-780.0	1078.3	1000.0	1255.0																						
11	3	-1.1352	3.1370	4.494	7097.3	3.48	0.9053E-02	1038.8	7019.5	-741.5	740.5	1000.0	1255.0																						
11	4	-1.5076	2.6691	4.494	7097.3	3.48	0.9053E-02	1038.8	7021.2	-741.5	585.4	1000.0	1255.0																						
11	5	-1.7872	2.1432	4.496	7098.0	3.47	0.9034E-02	1038.0	7021.3	-956.8	404.7	1000.0	1255.0																						
11	6	-1.9564	1.5861	4.495	7097.6	3.46	0.9044E-02	1038.4	7020.3	-1024.6	205.5	1000.0	1255.0																						
11	7	-2.0195	0.9440	4.489	7095.9	3.50	0.9090E-02	1040.5	7017.9	-1048.9	0.5	1000.0	1255.0																						
11	8	-1.9345	0.4131	4.476	7097.9	3.47	0.9038E-02	1038.1	7020.8	-1023.0	-204.4	1000.0	1255.0																						
11	9	-1.7850	-0.1418	4.497	7099.4	3.47	0.9026E-02	1037.6	7022.1	-956.5	-403.2	1000.0	1255.0																						
11	10	-1.5069	-0.6665	4.495	7097.6	3.46	0.9045E-02	1038.5	7021.8	-853.2	-584.6	1000.0	1255.0																						
11	11	-1.1369	-1.1352	4.494	7097.3	3.48	0.9052E-02	1038.4	7019.5	-740.8	-741.4	1000.0	1255.0																						
11	12	-1.0810	-1.8556	4.441	7080.5	3.72	0.9492E-02	1058.7	6953.2	-789.2	-1078.1	1000.0	1255.0																						
11	13	-1.0087	-2.4591	4.410	7070.2	3.87	0.9765E-02	1070.8	6889.0	-802.5	-1373.1	1000.0	1255.0																						
12	1	-1.4350	4.1734	4.407	7069.4	3.88	0.9786E-02	1071.8	6888.2	-867.2	1262.3	1000.0	1255.0																						
12	2	-1.4998	3.5051	4.440	7140.1	3.73	0.9502E-02	1059.2	6951.1	-949.2	950.7	1000.0	1255.0																						
12	3	-1.8556	3.0809	4.441	7080.5	3.72	0.9492E-02	1058.7	6953.2	-1078.1	789.8	1000.0	1255.0																						
12	4	-2.1465	2.6007	4.446	7081.9	3.70	0.9455E-02	1057.0	6954.6	-1188.1	612.1	1000.0	1255.0																						
12	5	-2.3614	2.0926	4.447	7082.4	3.69	0.9442E-02	1056.5	6954.8	-1270.8	420.1	1000.0	1255.0																						
12	6	-2.4329	1.5501	4.447	7082.2	3.69	0.9445E-02	1056.6	6954.2	-1323.7	211.5	1000.0	1255.0																						
12	7	-2.5408	0.9962	4.444	7081.5	3.70	0.9465E-02	1057.4	6952.8	-1344.2	-1.3	1000.0	1255.0																						
12	8	-2.4911	0.4443	4.447	7082.5	3.69	0.9440E-02	1056.4	6954.6	-1322.5	-213.2	1000.0	1255.0																						
12	9	-2.3590	-0.0339	4.448	7082.7	3.69	0.9443E-02	1056.1	6955.4	-1259.0	-420.1	1000.0	1255.0																						

Figure 8. (Continued)

SOLUTION SURFACE - X = 10.0000 (IN) PLANE 18

I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHO (LBM/FT3)	T (DEG K)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	P7 (LBF/IN2)	H (B/G/LBM)
12	10	-2.1457	-0.5981	4.447	7082.2	3.69	0.9445E-02	1056.6	6955.3	-1186.9	-610.8	1000.0	1255.0
12	11	-1.8581	-1.0736	4.442	7080.7	3.72	0.9486E-02	1056.4	6953.6	-1078.3	-787.8	1000.0	1255.0
12	12	-1.5051	-1.4956	4.440	7080.1	3.72	0.9502E-02	1059.1	6951.5	-950.7	-949.0	1000.0	1255.0
12	13	-1.4388	-2.1705	4.407	7069.2	3.89	0.9792E-02	1072.0	6888.0	-969.1	-1260.0	1000.0	1255.0
13	1	-1.8266	3.8302	4.406	7069.0	3.89	0.9797E-02	1072.2	6887.9	-1123.5	1123.5	1000.0	1255.0
13	2	-2.1707	3.4385	4.407	7069.2	3.89	0.9792E-02	1072.0	6888.0	-1260.0	1260.0	1000.0	1255.0
13	3	-2.4592	3.0086	4.410	7070.2	3.87	0.9765E-02	1070.8	6889.0	-1373.5	1373.5	1000.0	1255.0
13	4	-2.6896	2.5451	4.412	7070.9	3.86	0.9748E-02	1070.0	6890.6	-1462.5	1462.5	1000.0	1255.0
13	5	-2.8604	2.0474	4.414	7071.6	3.85	0.9728E-02	1069.2	6890.3	-1551.5	1551.5	1000.0	1255.0
13	6	-2.9652	1.5261	4.414	7071.5	3.85	0.9730E-02	1069.2	6890.3	-1575.4	1575.4	1000.0	1255.0
13	7	-3.0000	0.9972	4.414	7071.5	3.85	0.9730E-02	1069.2	6890.3	-1590.7	1590.7	1000.0	1255.0
13	8	-2.9646	0.4690	4.414	7071.7	3.85	0.9726E-02	1069.1	6890.6	-1575.1	1575.1	1000.0	1255.0
13	9	-2.8597	-0.0502	4.415	7071.9	3.85	0.9721E-02	1069.1	6890.6	-1530.6	1530.6	1000.0	1255.0
13	10	-2.6895	-0.5451	4.412	7071.2	3.86	0.9740E-02	1069.1	6889.9	-1462.6	1462.6	1000.0	1255.0
13	11	-2.4605	-1.0062	4.410	7070.5	3.87	0.9757E-02	1070.5	6889.3	-1374.0	1374.0	1000.0	1255.0
13	12	-2.1735	-1.4350	4.407	7069.4	3.88	0.9777E-02	1071.8	6888.2	-1261.3	1261.3	1000.0	1255.0
13	13	-1.8304	-1.8264	4.406	7069.1	3.89	0.9796E-02	1072.2	6887.9	-1123.5	1123.5	1000.0	1255.0

XSTEP REGULATION PARAMETERS

LIMITING POINT I = 13 AND J = 7 SAFETY FACTOR = 1.07818 DELTA X = 1.9830

EXECUTION TIME 806.2 SECS

Figure 8. (Continued)

#### 4. SAMPLE CASE 4

The fourth sample case is again identical to sample case 1 except for the initial-value surface, which is specified by tabular input. This option can only be employed for axisymmetric initial-value surfaces. In addition, a variation in the stagnation pressure and enthalpy across the initial-value line is specified, resulting in a rotational flow such as might occur in air breathing propulsion systems. The rotational flow option can only be employed when the thermally and calorically perfect gas option is specified. This limitation is a consequence of allowing for only a one-dimensional table for thermodynamic properties in the tabular property option in ARØSBL. This restriction can be easily removed by furnishing a three-dimensional table with static pressure, stagnation pressure, and stagnation enthalpy being the three independent variables. Thus, NAMELIST CNTRL is identical to case 1 except for IVSTYP which is set equal to 3. NAMELISTS WALSB and ARØSBL are the same as in sample case 1.

NAMELIST IVSL was constructed as follows. For four planes of symmetry, NPØS = 4. The initial-value line data were obtained from a source flow having the same properties as in sample case 1. Thus, XIVS was set at 0.174 inches, and YCIVS and ZCIVS were allowed to assume their default values of 0.0. The parameter MCIVS, PTCIVS, HCIVS, THECIV, PHICIV, ALPSRC and BETSRC are not specified for the tabular initial-value surface option. Twelve values of y, denoted by RIVS, were obtained at intervals of 0.1 inch across the initial-value surface of case 1. The Mach number MIVS and pitch angle THETIV were obtained by interpolation at the selected values of y. In order to illustrate the option of having variable stagnation pressure and enthalpy, PTIVS and HIVS were not fixed at the constant values of case 1, but were varied as shown in Figure 9. PTIVS decreased continually from 1000.0 psia at the centerline to 760.0 psia at the wall, while HIVS increased continually from 1255.0 Btu/lbm at the centerline to 1350.0 Btu/lbm at the wall. These variations are representative of the profiles which might occur in scramjet engines. This completes the specification of NAMELIST IVSL.

Figure 9 is a listing of data deck 4. Figure 10 presents selected portions of the computer output generated by sample case 4. This case required 101 seconds of central processor time and 135 seconds of peripheral processor time on the CDC 6500, and 210 seconds of central memory time on the IBM 7094.

SAMPLE CASE NO. 4  
 \$CNTRL IVSTYP=3,  
 NP=7,  
 XMAX=10.0 \$  
 \$WALSBL THETAT=36.0,  
 RE=10.0,  
 RE=4.0,  
 THETA=13.0 \$  
 \$AROSBL GAMMA=1.4,  
 RGAS=53.3 \$  
 \$IVSL MPOS=4,  
 XIVS=0.174,  
 RIVS=0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.01530,  
 MIVS=1.33,1.32,1.29,1.26,1.23,1.20,1.17,1.14,1.11,1.08,1.06,1.05,  
 PTIVS=1000.0,1000.0,990.0,970.0,940.0,910.0,880.0,850.0,820.0,790.0,760.0,  
 759.0,  
 HIVS=1255.0,1260.0,1270.0,1280.0,1290.0,1300.0,1310.0,1320.0,1330.0,1340.0,1350.0,  
 1352.0,  
 THETIV=0.0,0.5,1.3,2.3,3.0,5.0,6.0,7.0,8.0,9.0,9.9,10.0 \$

Figure 9. Data Deck 4

# THREE-DIMENSIONAL ANALYSIS OF SUPERSONIC NOZZLE FLOW

## ABSTRACT

THIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERSITY JET PROPULSION CENTER BY V. H. RANSOM AS A PART OF THE REQUIREMENTS OF AF CONTRACT NUMBER F33615-67-C-1068. THE CONTRACT WAS SPONSORED BY THE AFRO PROPULSION LABORATORY WRIGHT PATTERSON AFB, OHIO AND PRINCIPAL INVESTIGATORS FOR PURDUE UNIVERSITY WERE PROFESSORS H. DOYLE THOMPSON AND JOE L. MUEFFEL. THE EQUATIONS OF MOTION FOR A THREE-DIMENSIONAL SUPERSONIC FLOW ARE SOLVED USING A NUMERICAL METHOD OF CHARACTERISTICS HAVING SECOND-ORDER ACCURACY. THE FLOW VARIABLES MUST BE SPECIFIED OVER A SPACE-LIKE INITIAL VALUE SURFACE WHICH ADJOINS THE NOZZLE BOUNDARIES. THE NOZZLE GEOMETRY IS SPECIFIED BY MEANS OF THE SUBROUTINE NALSUB. THE NOZZLE MAY HAVE PLANES OF SYMMETRY AND THE THERMODYNAMIC PROPERTIES OF THE GAS ARE DETERMINED BY MEANS OF THE SUBROUTINE ARSUB.

## MAJOR ASSUMPTIONS

THE GASDYNAMIC MODEL IS BASED ON THE FOLLOWING ASSUMPTIONS. 1. CONTINUUM, 2. INVISCID, 3. STEADY, 4. STRICTLY ADIABATIC, 5. FROZEN OR EQUILIBRIUM CHEMICAL COMPOSITION, AND 6. SMOOTH INITIAL DATA AND BOUNDARIES.

## JCM TITLE

SAMPLE CASE NO. 4

## THERMODYNAMIC MODEL

A CALORICALLY AND THERMALLY PERFECT GAS IS SPECIFIED AND IS CHARACTERIZED BY THE FOLLOWING VALUES

SPECIFIC HEAT RATIO = 1.40000 AND GAS CONSTANT = 53.30000 (FY-LBA/LBM-DEG R)

## FLOW GEOMETRY

THE FLOW HAS 4 PLANES OF SYMMETRY PASSING THROUGH THE POINT-

X = 0.1740 (IN) Y = 0. (IN) Z = 0. (IN)

THE COMPONENTS OF THE OUTER NORMALS TO THE FIRST TWO PLANES ARE-

NX1 = 0. NY1 = 0. NZ1 = -1.000000

NX2 = 0. NY2 = -0.707107 NZ2 = 0.707107

Figure 10. Sample Case 4 Output

# NOZZLE GEOMETRY

AXISYMMETRIC CIRCLE-PARABOLA CONTOURED NOZZLE HAVING THE FOLLOWING PARAMETERS

THROAT AND AXIS COORDINATES

XT = 0. (IN) YC = 0. (IN) ZC = 0. (IN)

CONTOUR PARAMETERS

Ri = 1.0000 (IN) RC = 1.0000 (IN) XE = 10.0000 (IN) RE = 4.0000

THETAT = 36.0000 (DEG) THETA E = 13.0000 (DEG)

## TYPE OF INITIAL DATA SURFACE

THE INITIAL VALUES ARE AXISYMMETRIC AND ARE SPECIFIED BY TABULAR INPUT AS FUNCTIONS OF THE RADIAL COORDINATE

RADIUS (IN)	MACH NO.	THETA (DEG)	PSI (DEG)	PT (LBM/IN**2)	M (BTU/LBM)
0.	1.3300	0.	-0.000	1000.00	1255.00
0.1000	1.3200	0.500	-0.000	1000.00	1260.00
0.2000	1.2900	1.300	-0.000	970.00	1270.00
0.3000	1.2600	2.300	-0.000	970.00	1280.00
0.4000	1.2300	3.000	-0.000	940.00	1290.00
0.5000	1.2000	5.000	-0.000	910.00	1300.00
0.6000	1.1700	6.000	-0.000	880.00	1310.00
0.7000	1.1400	7.000	-0.000	850.00	1320.00
0.8000	1.1100	8.000	-0.000	820.00	1330.00
0.9000	1.0800	9.000	-0.000	790.00	1340.00
1.0000	1.0600	9.900	-0.000	760.00	1350.00
1.0153	1.0500	10.000	-0.000	759.00	1352.00

Figure 10. Sample Case 4 Output

INITIAL DATA - X = 0.1740 (IN)															
THRUST PARAMETERS															
CROSS SECTION AREA =		0.4036 (IN**2)		MASS FLOW =		2.4102 (LBM/SEC)									
XTHRUST =		-427.39 (LBF)		YTHRUST =		-27.20 (LBF)		ZTHRUST =		-11.30 (LBF)					
XCMPT =		0.00 (FT-LBF)		YCMPT =		-103.20 (FT-LBF)		ZCMPT =		249.15 (FT-LBF)					
BOUNDARY AND INTERIOR FLOW PARAMETERS															
I	J	Y	Z	M	Q	P	RMC	T	U	V	W	X	Y	Z	M
		(IN)	(IN)		(FT/SEC)	(LBM/IN**2)	(LBM/IN**3)	(DEG W)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(BTU/LBM-M)
1	1	0.1179	0.1179	1.05C	3457.3	377.87	0.2209E 00	4620.7	3444.2	429.4	429.4	155.0	155.0	1352.0	1352.0
1	2	0.8055	0.8180	1.05C	3457.3	377.87	0.2209E 00	4620.7	3444.2	481.8	363.1	159.0	159.0	1352.0	1352.0
1	3	0.8792	0.5076	1.050	3457.3	377.87	0.2209E 00	4620.7	3444.2	525.9	303.6	159.0	159.0	1352.0	1352.0
1	4	0.9800	0.3385	1.050	3457.3	377.87	0.2209E 00	4620.7	3444.2	561.1	212.4	159.0	159.0	1352.0	1352.0
1	5	0.9807	0.2628	1.05C	3457.3	377.87	0.2209E 00	4620.7	3444.2	585.6	157.2	155.0	155.0	1352.0	1352.0
1	6	1.0066	0.1135	1.05C	3497.3	377.87	0.2209E 00	4620.7	3444.2	607.1	79.3	159.0	159.0	1352.0	1352.0
1	7	1.0153	0.	1.050	3497.3	377.87	0.2209E 00	4620.7	3444.2	607.1	0.	759.0	759.0	1352.0	1352.0
2	2	0.6180	0.5180	1.0P5	3573.5	380.89	0.2279E 00	4515.5	3531.8	383.8	383.8	798.6	798.6	1337.5	1337.5
2	3	0.7071	0.5178	1.085	3573.5	380.89	0.2279E 00	4515.5	3531.8	439.1	319.0	798.6	798.6	1337.5	1337.5
2	4	0.7708	0.3428	1.085	3573.5	380.89	0.2279E 00	4515.5	3531.8	483.6	266.6	798.6	798.6	1337.5	1337.5
2	5	0.8313	0.2701	1.084	3573.5	380.89	0.2279E 00	4515.5	3531.8	516.2	167.7	798.6	798.6	1337.5	1337.5
2	6	0.8633	0.1367	1.085	3573.5	380.89	0.2279E 00	4515.5	3531.8	536.1	84.9	798.6	798.6	1337.5	1337.5
2	7	0.8741	0.	1.085	3573.5	380.89	0.2279E 00	4515.5	3531.8	542.7	0.	798.6	798.6	1337.5	1337.5
3	3	0.5076	0.3908	1.135	3681.9	378.65	0.2333E 00	4384.3	3653.1	325.7	325.7	844.5	844.5	1321.8	1321.8
3	4	0.5969	0.3908	1.135	3681.9	378.65	0.2333E 00	4384.3	3653.1	383.0	255.9	844.5	844.5	1321.8	1321.8
3	5	0.6632	0.2787	1.135	3681.9	378.65	0.2333E 00	4384.3	3653.1	425.5	176.2	844.5	844.5	1321.8	1321.8
3	6	0.7041	0.1401	1.135	3681.9	378.65	0.2333E 00	4384.3	3653.1	453.7	0.	844.5	844.5	1321.8	1321.8
3	7	0.7179	0.	1.135	3681.9	378.65	0.2333E 00	4384.3	3653.1	460.6	0.	844.5	844.5	1321.8	1321.8
4	4	0.3885	0.3885	1.195	3785.7	376.32	0.2393E 00	4249.5	3767.9	261.5	261.5	845.2	845.2	1304.9	1304.9
4	5	0.4758	0.2787	1.185	3785.7	376.32	0.2393E 00	4249.5	3767.9	320.3	184.9	845.2	845.2	1304.9	1304.9
4	6	0.5307	0.1422	1.185	3785.7	376.32	0.2393E 00	4249.5	3767.9	351.3	95.7	845.2	845.2	1304.9	1304.9
4	7	0.5495	0.	1.185	3785.7	376.32	0.2393E 00	4249.5	3767.9	369.9	0.	845.2	845.2	1304.9	1304.9
5	5	0.2628	0.2628	1.239	3890.0	371.94	0.2446E 00	4108.6	3685.9	129.3	129.3	948.9	948.9	1287.2	1287.2
5	6	0.3433	0.1422	1.239	3890.0	371.94	0.2446E 00	4108.6	3685.9	168.9	70.0	948.9	948.9	1287.2	1287.2
5	7	0.3716	0.	1.239	3890.0	371.94	0.2446E 00	4108.6	3685.9	182.9	0.	948.9	948.9	1287.2	1287.2
6	6	0.1325	0.1325	1.294	3952.4	360.85	0.2459E 00	3764.3	3991.5	58.1	58.1	991.8	991.8	1268.7	1268.7
6	7	0.1874	0.	1.294	3952.4	360.85	0.2459E 00	3764.3	3991.5	82.1	0.	991.8	991.8	1268.7	1268.7
7	7	0.	0.	1.330	4052.4	346.40	0.2420E 00	3867.0	4052.4	0.	0.	1000.0	1000.0	1255.0	1255.0
XSTEP REGULATION PARAMETERS															
LIMITING POINT I = 1 AND J = 7										SAFETY FACTOR =		0.0119			
												DELTA X =			
UNDRFLOW AT 62137 IN MQ															
UNDRFLOW AT 62137 IN MQ															
UNDRFLOW AT 62337 IN MQ															
UNDRFLOW AT 62337 IN MQ															
UNDRFLOW AT 62161 IN MQ															

Figure 10. (Continued)

SOLUTION SURFACE - X = 0.1859 (IN) PLANE 1

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA= 0.4053 (IN<sup>2</sup>) MASS FLOW RATE RATIO = 1.00187

XTHRUST = -428.76 (LBF) YTHRUST = -28.00 (LBF) ZTHRUST = -11.61 (LBF)

XDMT = -0.00 (FT-LBF) YDMT = -103.17 (FT-LBF) ZDMT = 249.07 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y	Z	M	Q	P	RHC	T	U	V	W	P1	H
		(IN)	(IN)	(FT/SEC)	(LBF/IN <sup>2</sup> )	(LBF/FT <sup>3</sup> )	(DEG RI)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN <sup>2</sup> )	(BTU/LBM)
1	1	0.7194	0.7194	1.162	3793.8	328.79	0.2000E 00	4440.6	3727.7	498.6	498.6	759.0	1352.0
1	2	0.8072	0.6194	1.162	3793.9	328.78	0.2000E 00	4440.6	2727.8	559.4	429.3	759.0	1352.0
1	3	0.8811	0.5087	1.162	3793.9	328.76	0.2000E 00	4440.6	3727.8	610.6	352.7	759.0	1352.0
1	4	0.9400	0.3894	1.162	3793.9	328.77	0.2000E 00	4440.6	3727.9	651.5	265.7	759.0	1352.0
1	5	0.9828	0.2633	1.162	3793.9	328.78	0.2000E 00	4440.6	3727.8	681.2	182.4	759.0	1352.0
1	6	1.0087	0.1328	1.162	3793.8	328.79	0.2000E 00	4440.6	3727.7	699.1	92.0	759.0	1352.0
1	7	1.0174	-0.0000	1.162	3793.8	328.79	0.2000E 00	4440.6	3727.7	705.1	-0.0	759.0	1352.0
2	2	0.6193	0.6193	1.114	3650.3	367.41	0.2221E 00	4469.2	3609.5	365.2	385.2	798.6	1337.5
2	3	0.7086	0.5148	1.114	3650.4	367.40	0.2221E 00	4469.2	3609.5	440.7	320.3	798.6	1337.5
2	4	0.7804	0.3976	1.114	3650.5	367.39	0.2221E 00	4469.2	3609.6	483.2	247.4	798.6	1337.5
2	5	0.8330	0.2707	1.114	3650.5	367.39	0.2221E 00	4469.2	3609.6	518.0	168.2	798.6	1337.5
2	6	0.8651	0.1370	1.114	3650.4	367.40	0.2221E 00	4469.2	3609.5	538.1	85.1	798.6	1337.5
2	7	0.8759	-0.0000	1.114	3650.4	367.41	0.2221E 00	4469.2	3609.5	544.8	-0.0	798.6	1337.5
3	3	0.5087	0.5087	1.155	3723.3	369.15	0.2291E 00	4352.6	3704.7	325.7	325.7	844.5	1321.8
3	4	0.5981	0.3997	1.155	3723.3	369.16	0.2291E 00	4352.6	3704.7	383.0	255.5	844.5	1321.8
3	5	0.6645	0.2753	1.155	3723.2	369.15	0.2291E 00	4352.6	3704.7	423.5	176.2	844.5	1321.8
3	6	0.7056	0.1403	1.155	3723.3	369.15	0.2291E 00	4352.6	3704.7	451.7	89.9	844.5	1321.8
3	7	0.7194	0.0000	1.155	3723.3	369.15	0.2291E 00	4352.6	3704.7	460.0	0.0	844.5	1321.8
4	4	0.3893	0.3893	1.202	3827.1	368.24	0.2356E 00	4223.2	3809.7	257.7	257.7	895.2	1304.9
4	5	0.4768	0.2753	1.202	3827.1	368.19	0.2356E 00	4223.1	3810.0	315.4	181.8	895.2	1304.9
4	6	0.5318	0.1425	1.202	3827.4	368.24	0.2356E 00	4223.2	3809.7	351.6	94.5	895.2	1304.9
4	7	0.5506	-0.0000	1.202	3827.1	368.19	0.2356E 00	4223.1	3810.0	364.4	-0.0	895.2	1304.9
5	5	0.2632	0.2632	1.253	3923.7	365.04	0.2413E 00	4086.7	3919.3	131.1	131.1	548.9	1287.2
5	6	0.3438	0.1424	1.253	3923.7	364.93	0.2413E 00	4086.3	3919.8	171.5	73.0	548.9	1287.2
5	7	0.3722	0.0000	1.253	3923.7	365.04	0.2413E 00	4086.7	3919.3	185.5	0.0	548.9	1287.2
6	6	0.1327	0.1327	1.304	4016.1	355.93	0.2435E 00	3948.5	4015.3	56.9	56.9	591.8	1268.7
6	7	0.1877	0.0000	1.304	4016.1	355.93	0.2435E 00	3948.5	4015.3	80.5	-0.0	591.8	1268.7
7	7	0.0000	-0.0000	1.336	4065.1	343.72	0.2407E 00	3858.4	4065.1	0.0	-0.0	1000.0	1255.0

XSTEP REGULATION PARAMETERS

LIMITING POINT I = 1 AND J = 7 SAFETY FACTOR = 0.70400 DELTA X = 0.0510

Figure 10. (Continued)

SOLUTION SURFACE - X = 10.0000 (IN) PLANE 22

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA= 6.2654 (IN\*2) MASS FLOW RATE RATIO = 0.99410

XTHRUST = -556.67 (LBF) YTHRUST = -65.30 (LBF) ZTHRUST = -27.17 (LBF)

XMOMT = -0.48 (FT-LBF) YMOMT = -302.10 (FT-LBF) ZMOMT = 731.64 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	X (IN)	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHO (LBF/FT3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN2)	H (BTU/LBM)
1	1	2.8284	2.8284	4.189	4.189	7258.4	3.90	0.8423E-02	1250.8	7072.3	1154.6	1154.5	755.0	1352.0
1	2	3.1694	2.4402	4.190	4.190	7258.8	3.89	0.8414E-02	1250.2	7072.8	1293.6	996.5	759.0	1352.0
1	3	3.4572	2.3119	4.193	4.193	7260.2	3.88	0.8386E-02	1248.6	7074.1	1409.7	824.7	759.0	1352.0
1	4	3.6888	1.5469	4.196	4.196	7261.2	3.86	0.8366E-02	1247.4	7075.1	1503.0	639.7	759.0	1352.0
1	5	3.8602	1.0484	4.197	4.197	7261.3	3.85	0.8354E-02	1246.7	7075.7	1573.4	439.4	759.0	1352.0
1	6	3.9650	0.5280	4.198	4.198	7262.0	3.85	0.8350E-02	1246.5	7075.8	1618.1	224.2	759.0	1352.0
1	7	4.0000	0.0000	4.198	4.198	7262.0	3.85	0.8350E-02	1246.5	7075.8	1633.6	0.0	759.0	1352.0
2	1	2.5087	2.5087	4.252	4.252	7243.1	3.78	0.8451E-02	1208.9	7110.2	976.8	976.8	798.6	1337.5
2	2	2.8637	2.0813	4.254	4.254	7244.1	3.77	0.8430E-02	1207.7	7112.7	1109.0	810.0	798.6	1337.5
2	3	3.1541	1.6017	4.259	4.259	7245.8	3.75	0.8394E-02	1205.6	7114.1	1223.3	628.3	798.6	1337.5
2	4	3.3674	1.0994	4.261	4.261	7246.5	3.74	0.8380E-02	1204.8	7114.1	1309.0	433.7	798.6	1337.5
2	5	3.5006	0.5582	4.261	4.261	7246.5	3.74	0.8381E-02	1204.8	7113.0	1366.4	221.7	798.6	1337.5
2	6	3.5501	0.0000	4.258	4.258	7245.5	3.75	0.8401E-02	1206.0	7111.3	1388.1	0.0	798.6	1337.5
3	1	2.1324	2.1324	4.335	4.335	7230.3	3.59	0.8378E-02	1158.7	7150.8	756.0	756.0	844.5	1321.8
3	2	2.4990	1.6641	4.337	4.337	7231.0	3.58	0.8363E-02	1157.8	7153.5	872.3	594.4	844.5	1321.8
3	3	2.7763	1.1398	4.340	4.340	7231.9	3.57	0.8342E-02	1156.7	7153.5	981.2	406.6	844.5	1321.8
3	4	2.9498	0.5856	4.338	4.338	7231.4	3.58	0.8354E-02	1157.4	7151.4	1051.9	207.7	844.5	1321.8
3	5	3.0149	0.0002	4.332	4.332	7229.2	3.61	0.8401E-02	1160.0	7148.3	1078.5	0.0	844.5	1321.8
4	1	1.7379	1.7380	4.446	4.446	7221.7	3.31	0.8133E-02	1098.7	7184.5	518.1	518.1	895.2	1304.9
4	2	2.1228	1.2115	4.445	4.445	7221.2	3.31	0.8145E-02	1099.4	7185.5	622.6	356.5	895.2	1304.9
4	3	2.3655	0.6303	4.442	4.442	7220.4	3.32	0.8162E-02	1100.3	7183.6	707.6	174.1	895.2	1304.9
4	4	2.4533	-0.0001	4.436	4.436	7218.2	3.35	0.8211E-02	1103.0	7180.2	740.3	-0.1	895.2	1304.9
5	1	1.2791	1.2794	4.671	4.671	7240.1	2.66	0.7169E-02	1001.2	7227.9	309.1	309.1	548.9	1287.2
5	2	1.6759	0.6666	4.667	4.667	7240.1	2.67	0.7191E-02	1002.4	7227.3	397.6	163.3	548.9	1287.2
5	3	1.8116	-0.0002	4.658	4.658	7237.5	2.70	0.7248E-02	1005.6	7224.3	436.8	-0.1	548.9	1287.2
6	1	0.7027	0.7028	5.056	5.056	7289.3	1.76	0.5483E-02	865.9	7285.7	160.6	160.6	991.8	1268.7
6	2	0.9925	-0.0001	5.056	5.056	7289.3	1.76	0.5482E-02	865.9	7285.8	225.8	-0.0	991.8	1268.7
7	1	0.0001	0.0000	5.325	5.325	7309.0	1.30	0.4490E-02	784.7	7309.0	0.0	0.0	1000.0	1255.0

XSTEP REGULATION PARAMETERS

LIMITING POINT I = 1 AND J = 7 SAFETY FACTOR = 1.07487 DELTA X = 1.7810

EXECUTION TIME 210.2 SECS

Figure 10. (Continued)

## 5. SAMPLE CASE 5

This sample case illustrates the nozzle contour option which specifies a super-elliptical nozzle with 2 planes of symmetry (i.e., NSYMMY = 2 and NPØS = 2). A uniform, parallel flow initial-value line (IVSTYP = 1) with seven points will be employed (NP = 7). The numerical solution will be carried out to a length of 3.75, which is the value specified for XMAX. These values complete the specification of NAMELIST CNTRL. This nozzle is geometrically similar to the nozzle presented in Figures 19 and 20 in Volume I. The only difference is a linear scale factor of 0.75 which must be applied to all dimensions in Figures 19 and 20 to obtain the present sample case. Thus, the isometric plot, the cross-section plots, and the polar pressure profiles presented there can be directly related to the present case.

The super-elliptical contour parameters are specified in NAMELIST WALSB. Thus, NSYMMY = 2, and YAXIS and ZAXIS are left at their default values. As usual, XT is left at its default value of zero. The next six parameters specify the contour intersections with the two planes of symmetry; thus, two values of each parameter must be specified. The initial contour is circular with RT = 0.75, 0.75 and RC = 0.75, 0.75. The point of tangency between the circular arc throat and the parabolic contour intersections with the two planes of symmetry are chosen as THETAT = 16.5, 7.0. The exit points in both planes are set at XE = 3.75, 3.75, and RE = 1.59, 1.07. The slopes at the exit points on the coordinate plane intersections are THETA E = 8.5, 3.0.

The remaining 14 parameters are used to specify the super-elliptical exponents in the flow space between the two planes of symmetry. Thus, one value for each parameter is required. The  $X_1$  coordinates of the three points selected to specify the  $X_1$  variation of EXPY are  $XY1 = -1.0$ ,  $XY2 = 0.20$ , and  $XY3 = 3.75$ . Likewise,  $XZ1 = -1.0$ ,  $XZ2 = 0.20$ , and  $XZ3 = 3.75$  for the specification of EXPZ. Note that  $XY1 = XZ1 = -1.0$  is completely upstream of the nozzle throat radius of curvature, which is 0.75 inches. This is immaterial since these values are used only to curve fit the exponents as functions of the  $X_1$  coordinate, and need not fall on the contour. In order to maintain an axisymmetric contour up to  $X_1 = 0.20$  inches, the exponents up to and including that point must be defined as 2.0, and the derivative of the exponent at the central point must be 0.0. Thus,  $EXPY1 = EXPY2 = EXPZ1 = EXPZ2 = 2.0$ , and  $DEDXY2 = DEDXZ2 = 0.0$ . The super-elliptical exponents downstream of the throat will be chosen large in order to generate a contour approaching a rectangular shape. Thus,  $EXPY3 = EXPZ3 = 10.0$ . This completes the specification of NAMELIST WALSB.

The same gas chemistry as specified in case 1 will be employed. Thus, NAMELIST ARØSBL is the same as in data deck 1.

For a super-elliptical contour with 2 planes of symmetry, NPØS = 2. XIVS, YCIVS and ZCIVS will be left at their default values. The remaining parameters are fixed at the values used in sample case 1, namely, MCIVS = 1.10, PTCIVS = 1000.0, and HCIVS = 1255.0. No pitch or yaw angles are desired, so the specification of NAMELIST IVSL is complete.

Figure 11 is a listing of data deck 5. Figure 12 presents selected portions of the computer printout for sample case 5. This case required 224 seconds of central processor time and 213 seconds of peripheral processor time on the CDC 6500, and 436 seconds of central memory time on the IBM 7094.

```

SAMPLE CASE NO. 5
$CNTRL      IVSTYP=1,
NP=7,
XMAX=3.75   $
$WALSBL     NSYMMY=2,
RT=0.75,0.75,
RC=0.75,0.75,
THETAT=16.5,7.0,
XE=3.75,3.75,
RE=1.59,1.07,
THETA E=8.5,3.0,
XY1=-1.0,
XY2=0.20,
XY3=3.75,
EXPY1=2.0,
EXPY2=2.0,
EXPY3=10.0,
DEDXY2=0.0,
XZ1=-1.0,
XZ2=0.20,
XZ3=3.75,
EXPZ1=2.0,
EXPZ2=2.0,
EXPZ3=10.0,
DEDXZ2=0.0   $
$AROSBL     GAMMA=1.4,
RGAS=53.3   $
$IVSL       NPOS=2,
MCIVS=1.10,
PTCIVS=1000.0,
HCIVS=1255.0 $

```

Figure 11. Data Deck 5

## ABSTRACT

THIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERSITY JET PROPULSION CENTER BY V. H. RANSOM AS A PART OF THE REQUIREMENTS OF AF CONTRACT NUMBER F33615-67-C-1068. THE CONTRACT WAS SPONSORED BY THE AERO PROPULSION LABORATORY WRIGHT PATTERSON AFB, OHIO AND PRINCIPAL INVESTIGATORS FOR PURDUE UNIVERSITY WERE PROFESSORS H. DOYLE THOMPSON AND JOE D. HOFFMAN.

THE EQUATIONS OF MOTION FOR A THREE-DIMENSIONAL SUPERSONIC FLOW ARE SOLVED USING A NUMERICAL METHOD OF CHARACTERISTICS HAVING SECOND-ORDER ACCURACY. THE FLOW VARIABLES MUST BE SPECIFIED OVER A SPACE-LIKE INITIAL VALUE SURFACE WHICH ADJOINS THE NOZZLE BOUNDARIES. THE NOZZLE GEOMETRY IS SPECIFIED BY MEANS OF THE SUBROUTINE WLSUB. THE NOZZLE MAY HAVE PLANES OF SYMMETRY AND THE THERMODYNAMIC PROPERTIES OF THE GAS ARE DETERMINED BY MEANS OF THE SUBROUTINE ARDSUB.

## MAJOR ASSUMPTIONS

THE GASDYNAMIC MODEL IS BASED ON THE FOLLOWING ASSUMPTIONS. 1. CONTINUUM, 2. INVISCID, 3. STEADY, 4. STRICTLY ADIABATIC, 5. FROZEN OR EQUILIBRIUM CHEMICAL COMPOSITION, AND 6. SMOOTH INITIAL DATA AND BOUNDARIES.

## JOB TITLE

SAMPLE CASE NO. 5

## THERMODYNAMIC MODEL

A CALORICALLY AND THERMALLY PERFECT GAS IS SPECIFIED AND IS CHARACTERIZED BY THE FOLLOWING VALUES

SPECIFIC HEAT RATIO = 1.40000 AND GAS CONSTANT = 53.30000 (FT-LBF/LBM-DEG R)

## FLOW GEOMETRY

THE FLOW HAS 2 PLANES OF SYMMETRY PASSING THROUGH THE POINT-

X = 0. (IN) Y = 0. (IN) Z = 0. (IN)

THE COMPONENTS OF THE OUTER NORMALS TO THE FIRST TWO PLANES ARE-

NX1 = 0. NY1 = 0. NZ1 = -1.000000

NX2 = 0. NY2 = -1.000000 NZ2 = 0.000000

Figure 12. Sample Case 5 Output

# NOZZLE GEOMETRY

## SUPERELLIPTICAL CIRCLE-PARABOLA NOZZLE HAVING THE FOLLOWING PARAMETERS

### THROAT AND AXIS COORDINATES

XY = 0. (IN) XTZ = 0. (IN) YCT = 0. (IN) ZCT = 0. (IN)

### X-Y COORDINATE PARAMETERS

RT = 0.7500 (IN) RC = 0.7500 (IN) KE = 3.7500 (IN) RE = 3.5900 (IN)

THETAT = 16.5000 (DEG) THETAL = 8.5000 (DEG)

### X-Z COORDINATE PARAMETERS

RT = 0.7500 (IN) RC = 0.7500 (IN) KE = 3.7500 (IN) RE = 3.0700 (IN)

THETAT = 7.0000 (DEG) THETAL = 3.0000 (DEG)

### SUPERELLIPTICAL EXPONENTS

XY1 = -1.0000 (IN) EY1 = 2.0000 XY2 = 0.2000 (IN) EY2 = 2.0000 XY3 = 3.7500 (IN) EY3 = 10.0000

XY1 = -1.0000 (IN) EY1 = 2.0000 XY2 = 0.2000 (IN) EY2 = 2.0000 XY3 = 3.7500 (IN) EY3 = 10.0000

DEKX2 = 0. (IN) DEKX2 = 0. (IN)

## TYPE OF INITIAL DATA SURFACE

THE FOLLOWING VALUES ARE CONSTANT OVER THE ENTIRE INITIAL DATA SURFACE LOCATED AT X = 0. (IN)

M = 1.1000 THETA = 0. (DEG) PHI = 0. (DEG) PT = 1000.00 (LBF/IN<sup>2</sup>) H = 1255.00 (BTU/LBM)

Figure 12. (Continued)

INITIAL DATA - X = 0. (IN)															
THRUST PARAMETERS															
CROSS SECTION AREA = 0.4405 (IN**2)				MASS FLOW = 3.2135 (LBM/SEC)											
XTHRUST = -555.01 (LBF)				YTHRUST = -0. (LBF)				ZTHRUST = -0. (LBF)							
XMMT = -0. (FT-LBF)				YMMT = -176.66 (FT-LBF)				ZMMT = 176.66 (FT-LBF)							
BOUNDARY AND INTERIOR FLOW PARAMETERS															
I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHC (LBM/FT3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PI (LBF/IN2)	H (BTU/LBM)		
1	1	0.5303	0.5303	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
1	2	0.5950	0.4566	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
1	3	0.6450	0.3750	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
1	4	0.6929	0.2870	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
1	5	0.7244	0.1941	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
1	6	0.7436	0.0979	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
1	7	0.7500	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
2	1	0.4566	0.5950	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
2	2	0.4566	0.4566	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
2	3	0.5224	0.3795	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
2	4	0.5753	0.2931	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
2	5	0.6141	0.1995	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
2	6	0.6377	0.1010	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
2	7	0.6457	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
3	1	0.3750	0.6495	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
3	2	0.3795	0.5224	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
3	3	0.3750	0.3750	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
3	4	0.4009	0.2946	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
3	5	0.4899	0.2029	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
3	6	0.5201	0.1035	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
3	7	0.5303	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
4	1	0.2870	0.6929	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
4	2	0.2931	0.5753	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
4	3	0.2946	0.4009	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
4	4	0.2870	0.2870	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
4	5	0.3515	0.2029	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
4	6	0.3921	0.1051	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
4	7	0.4059	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
5	1	0.1941	0.7244	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
5	2	0.1995	0.6141	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
5	3	0.2029	0.4899	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
5	4	0.2029	0.3515	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
5	5	0.1941	0.1941	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
5	6	0.2536	0.1050	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
5	7	0.2745	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
6	1	0.0979	0.7436	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
6	2	0.1010	0.6377	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
6	3	0.1035	0.5201	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
6	4	0.1051	0.3921	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
6	5	0.1050	0.2536	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
6	6	0.0979	0.0979	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
6	7	0.1364	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
7	1	0.0000	0.7500	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		
7	2	0.0000	0.6457	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0		

Figure 12. (Continued)

INITIAL DATA - X = 0. (IN)

I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHD (LBP/FT3)	T (DEG. F)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN2)	H (BTU/LBM)
7	3	0.0000	0.5303	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
7	4	0.0000	0.4059	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
7	5	0.0000	0.2745	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
7	6	0.0000	0.1384	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
7	7	0.	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0

XSTEP REGULATION PARAMETERS

LIMITING POINT I = 1 AND J = 6 SAFETY FACTOR = 0.64000 DELTA X = 0.0288

UNDERFLOW AT 33751 IN AC AND MQ.

UNDERFLOW AT 33751 IN MQ

UNDERFLOW AT 33751 IN MQ

UNDERFLOW AT 33751 IN MQ

UNDERFLOW AT 33751 IN MQ

Figure 12. (Continued)

SOLUTION SURFACE - X = 0.0288 (IN) PLANE 1  
 THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)  
 CROSS SECTION AREA = 0.4412 (IN\*\*2) MASS FLOW RATE RATIO = 1.00164  
 XTTHRUST = -556.38 (LBF) YTHRUST = -1.20 (LBF) ZTHRUST = -1.20 (LBF)  
 XMOMT = 0.00 (FT-LBF) YMOMT = -176.50 (FT-LBF) ZMOMT = 176.50 (FT-LBF)  
 BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	X	Y	Z	M	Q	P	RHG	T	U	V	W	PT	H
		(IN)	(IN)	(IN)		(FT/SEC)	(LBF/IN2)	(LBF/FT3)	(DEG R)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN2)	(BTU/LBM)
1	1	0.5307	0.5307	0.5307	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	101.9	101.9	1C0C.0	1255.0
1	2	0.5955	0.5569	0.5569	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	114.4	87.7	1C0C.0	1255.0
1	3	0.6500	0.5793	0.5793	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	124.8	72.1	1C0C.0	1255.0
1	4	0.6934	0.5943	0.5943	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	133.2	59.2	1C0C.0	1255.0
1	5	0.7250	0.5980	0.5980	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	139.2	37.3	1C0C.0	1255.0
1	6	0.7491	0.5980	0.5980	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	142.9	18.6	1C0C.0	1255.0
1	7	0.7506	0.5955	0.5955	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	144.1	0.0	1C0C.0	1255.0
2	1	0.4569	0.5566	0.5566	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
2	2	0.4566	0.5566	0.5566	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
2	3	0.5224	0.5795	0.5795	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
2	4	0.5753	0.5931	0.5931	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
2	5	0.6141	0.5995	0.5995	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
2	6	0.6377	0.6010	0.6010	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
2	7	0.6457	0.6000	0.6000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
3	1	0.3753	0.5224	0.5224	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	72.1	124.8	1C0C.0	1255.0
3	2	0.3795	0.5224	0.5224	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
3	3	0.3750	0.5224	0.5224	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
3	4	0.4409	0.5296	0.5296	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
3	5	0.4899	0.5209	0.5209	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
3	6	0.5201	0.5201	0.5201	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
3	7	0.5303	0.5303	0.5303	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
4	1	0.2872	0.6934	0.6934	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	55.2	133.2	1C0C.0	1255.0
4	2	0.2931	0.5753	0.5753	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
4	3	0.2946	0.5409	0.5409	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
4	4	0.2870	0.5780	0.5780	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
4	5	0.3515	0.5209	0.5209	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
4	6	0.3921	0.5051	0.5051	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
4	7	0.4059	0.5000	0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
5	1	0.1943	0.7250	0.7250	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	37.3	135.2	1C0C.0	1255.0
5	2	0.1995	0.6141	0.6141	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
5	3	0.2029	0.5899	0.5899	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
5	4	0.2029	0.5315	0.5315	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
5	5	0.1941	0.5191	0.5191	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
5	6	0.2386	0.5050	0.5050	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
5	7	0.2445	0.5000	0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
6	1	0.0960	0.7441	0.7441	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	18.6	142.9	1C0C.0	1255.0
6	2	0.1010	0.6377	0.6377	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
6	3	0.1035	0.5201	0.5201	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
6	4	0.1051	0.5191	0.5191	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
6	5	0.1050	0.5236	0.5236	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
6	6	0.0979	0.5074	0.5074	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
6	7	0.1384	0.5000	0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0
7	1	0.0000	0.7506	0.7506	1.204	3757.2	410.46	0.2732E 00	4059.1	3754.4	0.0	144.1	1C0C.0	1255.0
7	2	0.0000	0.6457	0.6457	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.0	0.0	1C0C.0	1255.0

Figure 12. (Continued)

Figure 12. (Continued)

SOLUTION SURFACE - I = 3.7500 (IN) PLANE 28

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA = 1.6735 (IN^2) MASS FLOW RATE RATIO = 0.99255

XTHRUST = -674.39 (LBF) YTHRUST = -65.34 (LBF) ZTHRUST = -21.24 (LBF)

XMOMT = 16.36 (FT-LBF) YMOMT = -280.03 (FT-LBF) ZMOMT = 312.77 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	X (IN)	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN^2)	RHO (LBF/FT^3)	Y (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN^2)	M (G/TU/LBM)
1	1	1.4729	1.0051	2.607	2.607	6016.7	49.61	0.6039E-01	2219.3	5901.5	1065.3	488.5	1C0C.0	1255.0
1	2	1.5454	0.9305	2.595	2.595	6005.7	50.48	0.6115E-01	2230.4	5894.6	1036.6	503.1	1C0C.0	1255.0
1	3	1.5795	0.8132	2.601	2.601	6011.3	50.04	0.6076E-01	2224.8	5917.3	956.9	453.2	1C0C.0	1255.0
1	4	1.5889	0.6520	2.633	2.633	6042.6	47.60	0.5863E-01	2193.3	5961.2	905.3	365.1	1C0C.0	1255.0
1	5	1.5900	0.4535	2.677	2.677	6084.4	44.47	0.5586E-01	2151.1	6012.4	899.2	248.4	1C0C.0	1255.0
1	6	1.5898	0.2315	2.707	2.707	6112.2	42.46	0.5404E-01	2122.8	6043.8	903.6	123.6	1C0C.0	1255.0
1	7	1.5900	0.0000	2.717	2.717	6120.6	41.87	0.5350E-01	2114.3	6053.3	904.7	0.0	1C0C.0	1255.0
2	1	1.5524	1.0461	2.639	2.639	6048.1	47.18	0.5827E-01	2187.8	5942.2	1043.9	425.2	1C0C.0	1255.0
2	2	1.4504	0.8273	2.720	2.720	6123.3	41.68	0.5332E-01	2111.6	6037.2	955.2	366.0	1C0C.0	1255.0
2	3	1.3485	0.7366	2.702	2.702	6107.1	42.83	0.5437E-01	2128.1	6022.3	945.5	305.7	1C0C.0	1255.0
2	4	1.4001	0.6029	2.709	2.709	6114.0	42.33	0.5392E-01	2121.0	6036.6	911.9	312.5	1C0C.0	1255.0
2	5	1.4244	0.4212	2.735	2.735	6137.5	40.68	0.5241E-01	2097.1	6085.9	908.4	219.5	1C0C.0	1255.0
2	6	1.4346	0.2210	2.757	2.757	6156.8	39.36	0.5119E-01	2077.1	6087.8	912.0	113.8	1C0C.0	1255.0
2	7	1.4369	0.0001	2.764	2.764	6162.8	38.95	0.5081E-01	2071.1	6095.1	911.1	0.1	1C0C.0	1255.0
3	1	1.1633	1.0643	2.706	2.706	6110.9	42.56	0.5413E-01	2124.2	6021.0	979.8	360.5	1C0C.0	1255.0
3	2	1.1146	0.8843	2.766	2.766	6164.8	38.81	0.5088E-01	2069.0	6086.2	920.6	340.8	1C0C.0	1255.0
3	3	1.0284	0.6480	2.835	2.835	6224.5	34.92	0.4699E-01	2007.5	6160.1	848.0	279.7	1C0C.0	1255.0
3	4	1.1433	0.5397	2.810	2.810	6202.8	36.31	0.4832E-01	2029.9	6134.7	879.7	256.7	1C0C.0	1255.0
3	5	1.2083	0.3087	2.808	2.808	6201.5	36.39	0.4840E-01	2031.3	6134.8	880.3	192.8	1C0C.0	1255.0
3	6	1.2387	0.2033	2.816	2.816	6208.5	35.94	0.4797E-01	2024.0	6143.4	890.8	103.7	1C0C.0	1255.0
3	7	1.2468	0.0001	2.819	2.819	6210.8	35.79	0.4783E-01	2021.7	6147.2	886.4	0.0	1C0C.0	1255.0
4	1	0.9513	1.0694	2.808	2.808	6201.2	36.41	0.4841E-01	2031.5	6132.6	859.2	329.9	1C0C.0	1255.0
4	2	0.9130	0.9159	2.842	2.842	6230.4	34.55	0.4664E-01	2001.3	6167.7	822.8	217.1	1C0C.0	1255.0
4	3	0.8554	0.7201	2.885	2.885	6265.6	32.38	0.4453E-01	1964.6	6212.6	764.8	178.1	1C0C.0	1255.0
4	4	0.7840	0.4745	2.923	2.923	6296.0	30.58	0.4275E-01	1932.9	6253.0	707.8	197.0	1C0C.0	1255.0
4	5	0.9196	0.3514	2.894	2.894	6272.8	31.95	0.4411E-01	1957.2	6221.4	785.1	160.1	1C0C.0	1255.0
4	6	0.9872	0.1871	2.885	2.885	6265.4	32.39	0.4454E-01	1964.8	6212.0	811.5	90.1	1C0C.0	1255.0
4	7	1.0076	0.0000	2.862	2.862	6263.2	32.53	0.4467E-01	1967.2	6210.6	810.1	0.0	1C0C.0	1255.0
5	1	0.6662	1.0700	2.915	2.915	6289.8	30.94	0.4311E-01	1939.4	6247.0	655.4	321.8	1C0C.0	1255.0
5	2	0.6524	0.9310	2.934	2.934	6304.8	30.07	0.4274E-01	1923.6	6283.9	648.6	304.6	1C0C.0	1255.0
5	3	0.6178	0.7620	2.952	2.952	6319.1	29.26	0.4142E-01	1908.6	6284.5	603.0	268.1	1C0C.0	1255.0
5	4	0.5801	0.5573	2.966	2.966	6329.8	28.66	0.4081E-01	1897.4	6301.5	559.0	209.8	1C0C.0	1255.0
5	5	0.5292	0.3095	2.971	2.971	6334.0	28.43	0.4037E-01	1892.9	6312.3	505.3	120.2	1C0C.0	1255.0
5	6	0.5730	0.1733	2.948	2.948	6315.8	29.45	0.4161E-01	1912.1	6284.3	528.4	72.3	1C0C.0	1255.0
5	7	0.7161	0.0000	2.942	2.942	6310.9	29.72	0.4189E-01	1917.2	6272.5	649.3	0.0	1C0C.0	1255.0
6	1	0.3425	1.0664	2.995	2.995	6351.9	27.44	0.3957E-01	1874.0	6332.5	350.9	341.0	1C0C.0	1255.0
6	2	0.3404	0.9301	3.003	3.003	6358.0	27.11	0.3922E-01	1867.5	6340.1	370.9	259.8	1C0C.0	1255.0
6	3	0.3216	0.7821	3.011	3.011	6364.5	26.77	0.3887E-01	1860.7	6349.6	342.4	258.4	1C0C.0	1255.0
6	4	0.3108	0.6005	3.012	3.012	6364.8	26.75	0.3885E-01	1860.3	6353.2	324.6	206.5	1C0C.0	1255.0
6	5	0.2956	0.3942	3.000	3.000	6356.3	27.21	0.3932E-01	1869.4	6347.8	295.0	144.2	1C0C.0	1255.0
6	6	0.2654	0.1525	2.993	2.993	6350.7	27.51	0.3963E-01	1875.2	6345.0	264.2	56.0	1C0C.0	1255.0
6	7	0.3729	-0.0000	2.984	2.984	6343.8	27.89	0.4002E-01	1882.6	6333.1	367.4	0.0	1C0C.0	1255.0
7	1	-0.0000	1.0700	3.016	3.016	6366.4	26.67	0.3876E-01	1858.6	6357.7	-0.1	333.2	1C0C.0	1255.0
7	2	-0.0001	0.9360	3.026	3.026	6375.5	26.18	0.3826E-01	1849.0	6368.7	-0.0	295.0	1C0C.0	1255.0

Figure 12. (Continued)

SOLUTION SURFACE -									
I J		X Y		Z		X = 3.7500 (IN)		PLANE 28	
		(IN)		(IN)					
						Q		P	
						(FT/SEC)		(LBF/IN2)	
						M		RNG	
								(LBF/FT3)	
								(DEG RI)	
								T	
								(FT/SEC)	
								U	
								(FT/SEC)	
								V	
								(FT/SEC)	
								W	
								(FT/SEC)	
								PT	
								(LBF/IN2)	
								H	
								(BTU/LBM)	

## 6. SAMPLE CASE 6

Sample case 6 is designed to illustrate the nozzle contour option of a completely general super-elliptical contour. Thus, all four sets of parameters specifying the contour intersections with the four coordinate planes must be input, as must all four sets of parameters specifying the super-elliptical exponents in each of the four quadrants of the flow space. NAMELISTS CNTRL, ARSBL and IVSL are specified to be the same as for sample case 5 with the exception of XMAX = 10.0 so a longer nozzle can be specified, and NPQS which is left at its default value of zero. Thus, these three NAMELISTS do not need to be redefined.

The general super-elliptical contour specification is defined in NAMELIST WALSB. For such a contour, NSYMMY = 3. YAXIS and ZAXIS are left at their default values of 0.0. The next seven parameters, each containing four values, specify the contour intersections with the  $(X_1, X_2)$ ,  $(X_1, X_3)$ ,  $(X_1, -X_2)$  and  $(X_1, -X_3)$  coordinate planes. All four intersections are composed of circular arcs centered at  $X_1 = 0.0$  joined tangentially to general parabolas. Thus, the default values of XT are employed. The local throats are all chosen as one inch, thus  $RT = 1.0, 1.0, 1.0, 1.0$ . These are the default values of RT, so they could be omitted if desired. The radii of curvature of all four circular arc segments is chosen as 0.5 inch, so  $RC = 0.5, 0.5, 0.5, 0.5$ . The angles at the points of tangency between the circular arcs and the parabolas are specified as THETAT = 30.0, 35.0, 30.0, 40.0. The final points of all four contour coordinate plane intersections are to be specified at  $X_1 = 10.0$  inches, so  $XE = 10.0, 10.0, 10.0, 10.0$ . The radii to the contour intersections at the exit are  $RE = 4.0, 5.0, 4.0, 6.0$ , and the wall slopes at these points are THETA = 5.0, 7.0, 5.0, 10.0.

The next 14 parameters, each containing 4 values specify the variation of the super-elliptical exponents in the 4 quadrants of the flow space. The order of the 4 values of each parameter in relation to the 4 quadrants is discussed in Section IV.4. The  $X_1$  coordinates of the four first points used to specify the variation of EXPY are  $XY1 = 0.0, 0.0, 0.0, 0.0$ . The second points are  $XY2 = 1.0, 1.0, 1.0, 1.0$ , and the third points are  $XY3 = 10.0, 10.0, 10.0, 10.0$ . The values of EXPY at these points are all four  $EXPY1 = 2.0$ , all four  $EXPY2 = 2.0$ , and  $EXPY3 = 2.0, 5.0, 5.0, 2.0$ . The derivatives of the exponent at the middle points are set equal to zero in order to maintain an axisymmetric initial contour; thus,  $DEDX2 = 0.0, 0.0, 0.0, 0.0$ . Similar specifications must be given for EXPZ, the exponent of the z-axis term in the super-elliptical equation, Eq. (1). Thus, all four  $XZ1 = 0.0$ , all four  $XZ2 = 1.0$ , and all four  $XZ3 = 10.0$ . The values of EXPZ at these twelve points are all four  $EXPZ1 = 2.0$ , all four  $EXPZ2 = 2.0$ , and  $EXPZ3 = 5.0, 2.0, 5.0, 2.0$ . The derivatives at the midpoints,  $DEDX2$ , are all four set equal to zero to maintain the axisymmetric shape up to that point. This completes the specification of NAMELIST WALSB.

Figure 13 presents data deck 6. Selected portions of the computer output are illustrated in Figure 14. Sample case 6 required 662 seconds of central processor time and 156 seconds of peripheral processor time on the CDC 6500, and 1192 seconds of central memory time on the IBM 7094.

```

SAMPLE CASE NO. 6
$CNTRL      IVSTYP=1,
NP=7,
XMAX=10.0    $
$WALSBL      NSYMMY=3,
RT=1.0,1.0,1.0,1.0,
RC=0.5,0.5,0.5,0.5,
THETAT=30.0,35.0,30.0,40.0,
XE=10.0,10.0,10.0,10.0,
RE=4.0,5.0,4.0,6.0,
THETA E = 5.0,7.0,5.0,10.0,
XY1=0.0,0.0,0.0,0.0,
XY2=1.0,1.0,1.0,1.0,
XY3=10.0,10.0,10.0,10.0,
EXPY1=2.0,2.0,2.0,2.0,
EXPY2=2.0,2.0,2.0,2.0,
EXPY3=2.0,5.0,5.0,2.0,
DEDXY2=0.0,0.0,0.0,0.0,
XZ1=0.0,0.0,0.0,0.0,
XZ2=1.0,1.0,1.0,1.0,
XZ3=10.0,10.0,10.0,10.0,
EXPZ1=2.0,2.0,2.0,2.0,
EXPZ2=2.0,2.0,2.0,2.0,
EXPZ3=5.0,2.0,5.0,2.0,
DEDXZ2=0.0,0.0,0.0,0.0 $
$AROSBL      GAMMA=1.4,
RGAS=53.3    $
$IVSL        MCIVS=1.10,
PTCIVS=1000.0,
HCIVS=1255.0 $

```

Figure 13. Data Deck 6

# THREE-DIMENSIONAL ANALYSIS OF SUPERSONIC NOZZLE FLOW

## ABSTRACT

THIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERSITY JET PROPULSION CENTER BY V. H. RANSOM AS A PART OF THE REQUIREMENTS OF AF CONTRACT NUMBER F33615-67-C-1068. THE CONTRACT WAS SPONSORED BY THE AERO PROPULSION LABORATORY WRIGHT PATTERSON AFB, OHIO AND PRINCIPAL INVESTIGATORS FOR PURDUE UNIVERSITY WERE PROFESSORS M. DOYLE THOMPSON AND JOE J. HOFFMAN.

THE EQUATIONS OF MOTION FOR A THREE-DIMENSIONAL SUPERSONIC FLOW ARE SOLVED USING A NUMERICAL METHOD OF CHARACTERISTICS HAVING SECOND-ORDER ACCURACY. THE FLOW VARIABLES MUST BE SPECIFIED OVER A SPACE-LIKE INITIAL VALUE SURFACE WHICH ADJOINS THE NOZZLE BOUNDARIES. THE NOZZLE GEOMETRY IS SPECIFIED BY MEANS OF THE SUBROUTINE WALSUB. THE NOZZLE MAY HAVE PLANES OF SYMMETRY AND THE THERMODYNAMIC PROPERTIES OF THE GAS ARE DETERMINED BY MEANS OF THE SUBROUTINE AMOSUB.

## MAJOR ASSUMPTIONS

THE GASDYNAMIC MODEL IS BASED ON THE FOLLOWING ASSUMPTIONS. 1. CONTINUUM, 2. INVISCID, 3. STEADY, 4. STRICTLY ADIABATIC, 5. FROZEN OR EQUILIBRIUM CHEMICAL COMPOSITION, AND 6. SPECIFY INITIAL DATA AND BOUNDARIES.

## JOB TITLE

SAMPLE CASE NO. 6

## THERMODYNAMIC MODEL

A CALORICALLY AND THERMALLY PERFECT GAS IS SPECIFIED AND IS CHARACTERIZED BY THE FOLLOWING VALUES

SPECIFIC HEAT RATIO = 1.40000 AND GAS CONSTANT = 53.30000 (FT-LBF/LBM-DEG R)

## FLOW GEOMETRY

NO PLANES OF SYMMETRY

Figure 14. Sample Case 6 Output

# NOZZLE GEOMETRY

SUPERELLIPTICAL CIRCLE-PARABOLA NOZZLE HAVING NO PLANES OF SYMMETRY

## AXIS COORDINATES

YCT = 0. (IN) ZCT = 0. (IN)

## X-Y(POSITIVE) CONTOUR PARAMETERS

XT = 0. (IN) RT = 1.0000 (IN) RC = 0.5000 (IN) XE = 10.0000 (IN) RE = 4.0000 (IN)

THETAT = 30.0000 (DEG) THETAET = 5.0000 (DEG)

## X-Y(NEGATIVE) CONTOUR PARAMETERS

XT = 0. (IN) RT = 1.0000 (IN) RC = 0.5000 (IN) XE = 10.0000 (IN) RE = 4.0000 (IN)

THETAT = 30.0000 (DEG) THETAET = 5.0000 (DEG)

## X-Z(POSITIVE) CONTOUR PARAMETERS

XT = 0. (IN) RT = 1.0000 (IN) RC = 0.5000 (IN) XE = 10.0000 (IN) RE = 5.0000 (IN)

THETAT = 35.0000 (DEG) THETAET = 7.0000 (DEG)

## X-Z(NEGATIVE) CONTOUR PARAMETERS

XT = 0. (IN) RT = 1.0000 (IN) RC = 0.5000 (IN) XE = 10.0000 (IN) RE = 6.0000 (IN)

THETAT = 40.0000 (DEG) THETAET = 10.0000 (DEG)

## SUPERELLIPTICAL EXPONENTS - QUADRANT 1

XY1 = 0. (IN) EY1 = 2.0000 XY2 = 1.0000 (IN) EY2 = 2.0000 XY3 = 10.0000 (IN) EY3 = 2.0000

XZ1 = 0. (IN) EZ1 = 2.0000 XZ2 = 1.0000 (IN) EZ2 = 2.0000 XZ3 = 10.0000 (IN) EZ3 = 5.0000

DEDXY2 = 0. (IN\*\*1) DEDXZ2 = 0. (IN\*\*1)

## SUPERELLIPTICAL EXPONENTS - QUADRANT 2

XY1 = 0. (IN) EY1 = 2.0000 XY2 = 1.0000 (IN) EY2 = 2.0000 XY3 = 10.0000 (IN) EY3 = 5.0000

XZ1 = 0. (IN) EZ1 = 2.0000 XZ2 = 1.0000 (IN) EZ2 = 2.0000 XZ3 = 10.0000 (IN) EZ3 = 2.0000

DEDXY2 = 0. (IN\*\*1) DEDXZ2 = 0. (IN\*\*1)

## SUPERELLIPTICAL EXPONENTS - QUADRANT 3

XY1 = 0. (IN) EY1 = 2.0000 XY2 = 1.0000 (IN) EY2 = 2.0000 XY3 = 10.0000 (IN) EY3 = 5.0000

XZ1 = 0. (IN) EZ1 = 2.0000 XZ2 = 1.0000 (IN) EZ2 = 2.0000 XZ3 = 10.0000 (IN) EZ3 = 5.0000

DEDXY2 = 0. (IN\*\*1) DEDXZ2 = 0. (IN\*\*1)

Figure 14. (Continued)

SUPERELLIPTICAL EXPONENTS - QUADRANT 4

XY1 = 0.	(IN)	XY1 = 2.0000	XY2 = 1.0000 (IN)	XY2 = 2.0000	XY2 = 10.0000 (IN)	XY3 = 2.0000
XZ1 = 0.	(IN)	XZ1 = 2.0000	XZ2 = 1.0000 (IN)	XZ2 = 2.0000	XZ2 = 10.0000 (IN)	XZ3 = 2.0000
DEOXY2 = 0.	(IN**1)	DEOXY2 = 0.	(IN**1)			

TYPE OF INITIAL DATA SURFACE

THE FOLLOWING VALUES ARE CONSTANT OVER THE ENTIRE INITIAL DATA SURFACE LOCATED AT X = C. (IV)

M = 1.1000	THETA = 0.	(DEG)	PHI = 0.	(DEG)	PT = 1000.00 (LBF/IN**2)	H = 1255.00 (RTU/LBF)
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Figure 14. (Continued)

INITIAL DATA - X = 0. (IN)

THRUST PARAMETERS

CROSS SECTION AREA = 3.1320 (IN\*\*2) MASS FLOW = 22.8679 (LBM/SEC)  
 XTHRUST = -3951.83 (LBF) YTHRUST = -0. (LBF) ZTHRUST = -0. (LBF)  
 XMOMT = -0. (FT-LBF) YMOMT = 0.00 (FT-LBF) ZMOMT = -0.00 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

J	X (IN)	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RMC (LBM/FT3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PI (LBF/IN2)	M (LBM/IN)
1 1	0.7070	0.7070	0.7070	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 2	0.7933	0.6087	0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 3	0.8660	0.5000	0.3826	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 4	0.9238	0.3826	0.2588	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 5	0.9654	0.2588	0.1305	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 6	0.9913	0.1305	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 7	1.0000	0.	-0.1305	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 8	0.9913	-0.1305	-0.2588	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 9	0.9654	-0.2588	-0.3826	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 10	0.9238	-0.3826	-0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 11	0.8660	-0.5000	-0.6087	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 12	0.7933	-0.6087	-0.7070	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
1 13	0.7070	-0.7070	-0.7933	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 1	0.6087	0.7933	0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 2	0.6087	0.6087	0.3826	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 3	0.6965	0.5060	0.2588	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 4	0.7670	0.3908	0.1347	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 5	0.8108	0.2660	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 6	0.8502	0.1347	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 7	0.8609	0.	-0.1347	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 8	0.8502	-0.1347	-0.2660	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 9	0.8188	-0.2660	-0.3908	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 10	0.7670	-0.3908	-0.5060	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 11	0.6965	-0.5060	-0.6087	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 12	0.6087	-0.6087	-0.7933	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
2 13	0.5000	-0.7933	-0.8660	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 1	0.5000	0.6965	0.5060	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 2	0.5060	0.5060	0.3908	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 3	0.5999	0.3908	0.2588	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 4	0.5079	0.2588	0.1305	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 5	0.4532	0.1305	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 6	0.6934	0.1379	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 7	0.7071	0.	-0.1379	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 8	0.6934	-0.1379	-0.2588	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 9	0.6532	-0.2588	-0.3908	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 10	0.5879	-0.3908	-0.5060	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 11	0.4999	-0.5060	-0.6087	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 12	0.5060	-0.6087	-0.7933	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
3 13	0.5000	-0.7933	-0.8660	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
4 1	0.3826	0.7670	0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
4 2	0.3908	0.5000	0.3826	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
4 3	0.3908	0.3826	0.2588	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
4 4	0.3826	0.2588	0.1305	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0
4 5	0.4687	0.1305	0.	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1000.0	1255.0

Figure 14. (Continued)

Figure 14. (Continued)

INITIAL DATA -																			
I	J	Y	Z	X	O	M	Q	P	RHO	T	U	V	W	PI	H				
		(IN)	(IN)				(FT/SEC)	(LBF/IN2)	(LBF/FT3)	(DEG H)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN2)	(LBF/IN2)				
8	8	-0.1305	-0.1305			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
8	9	-0.1401	-0.1401			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
8	10	-0.1401	-0.1401			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
8	11	-0.1379	-0.1379			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
8	12	-0.1347	-0.1347			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
8	13	-0.1305	-0.1305			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	1	-0.2568	0.8188			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	2	-0.2706	0.6312			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	3	-0.2706	0.6312			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	4	-0.2706	0.6312			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	5	-0.2588	0.2588			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	6	-0.3381	0.1401			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	7	-0.3660	0.0000			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	8	-0.3381	-0.1401			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	9	-0.2588	-0.2588			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	10	-0.2706	-0.2706			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	11	-0.2706	-0.2706			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	12	-0.2660	-0.8188			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
9	13	-0.2588	-0.2588			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	1	-0.3826	0.3238			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	2	-0.3908	0.7670			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	3	-0.3928	0.5879			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	4	-0.3826	0.3826			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	5	-0.4687	0.2706			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	6	-0.5227	0.1401			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	7	-0.5412	0.0000			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	8	-0.5227	-0.1401			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	9	-0.4687	-0.2706			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	10	-0.3826	-0.3826			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	11	-0.3928	-0.5079			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	12	-0.3908	-0.7670			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
10	13	-0.3826	-0.3826			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	1	-0.5000	0.8660			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	2	-0.5060	0.6965			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	3	-0.4999	0.4999			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	4	-0.5879	0.3928			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	5	-0.6532	0.2706			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	6	-0.6934	0.1379			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	7	-0.7071	0.0000			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	8	-0.6934	-0.1379			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	9	-0.6532	-0.2706			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	10	-0.5879	-0.3928			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	11	-0.4999	-0.4999			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	12	-0.5060	-0.6965			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
11	13	-0.5000	-0.8660			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	1	-0.6087	0.7933			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	2	-0.6027	0.6087			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	3	-0.6465	0.5060			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	4	-0.7670	0.3908			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	5	-0.8188	0.2660			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	6	-0.8502	0.1347			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	7	-0.8609	0.0000			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	8	-0.8502	-0.1347			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				
12	9	-0.8188	-0.2660			1.100	3459.2	468.35	0.3002E 00	4215.0	3459.2	0.	0.	1000.0	1255.0				

Figure 14. (Continued)

INITIAL DATA -										(IN)									
I	J	Y	Z	M	Q	P	RHC	I	U	V	W	PI	M	PI	M	PI	M	PI	M
12	10	-0.7670	-0.3908	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
12	11	-0.6965	-0.5060	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
12	12	-0.6087	-0.6087	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
12	13	-0.6087	-0.7933	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	1	-0.7070	0.7070	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	2	-0.7933	0.6087	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	3	-0.8660	0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	4	-0.9238	0.3826	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	5	-0.9658	0.2588	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	6	-0.9913	0.1305	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	7	-1.0000	0.0000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	8	-0.9913	-0.1305	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	9	-0.9658	-0.2588	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	10	-0.9238	-0.3826	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	11	-0.8660	-0.5000	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	12	-0.7933	-0.6087	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0
13	13	-0.7070	-0.7070	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	0.	0.	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0	1C0C.0	1255.0

XSTEP REGULATION PARAMETERS

LIMITING POINT I = 1 AND J = 5 SAFETY FACTOR = 0.64000 DELTA X = 0.0384

UNDRFLCW AT 33751 IN AC AND MQ.

UNDRFLCW AT 33751 IN MQ

UNDRFLCW AT 33751 IN MQ

UNDRFLCW AT 33751 IN MQ

UNDRFLCW AT 33751 IN MQ

Figure 14. (Continued)

SOLUTION SURFACE - X = 0.0364 (IN) PLANE 1

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA = 3.1415 (IN\*\*2) MASS FLOW RATE RATIO = 1.00491

XTHRUST = -3960.89 (LBF) YTHRUST = -0.00 (LBF) ZTHRUST = -0.00 (LBF)

YMCMT = 0.00 (FT-LBF) YMCMT = 0.00 (FT-LBF) ZMCMT = 0.00 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	X	Y	Z	M	Q	P	RHC	T	U	V	W	PT	M
		(IN)	(IN)	(IN)		(FT/SEC)	(LBF/LIN2)	(LBF/FT3)	(LBS)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(BTU/LBF)	(BTU/LBF)
1	1	0.7081	0.7081	0.7081	1.306	3997.8	358.02	0.24786	3903.6	3986.1	216.9	216.9	1000.0	1255.0
1	2	0.7945	0.6097	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	243.3	186.7	1000.0	1255.0
1	3	0.8673	0.5007	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	265.6	153.3	1000.0	1255.0
1	4	0.9252	0.3832	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	283.4	117.4	1000.0	1255.0
1	5	0.9673	0.2592	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	296.2	79.4	1000.0	1255.0
1	6	0.9929	0.1307	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	304.1	40.0	1000.0	1255.0
1	7	1.0013	0.0	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	304.1	0.0	1000.0	1255.0
1	8	0.9929	-0.1107	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	304.1	-40.0	1000.0	1255.0
1	9	0.9673	-0.2592	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	296.2	-79.4	1000.0	1255.0
1	10	0.9252	-0.3832	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	283.4	-117.4	1000.0	1255.0
1	11	0.8673	-0.5007	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	265.6	-153.3	1000.0	1255.0
1	12	0.7945	-0.6097	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	243.3	-186.7	1000.0	1255.0
1	13	0.7081	-0.7081	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	216.9	-216.9	1000.0	1255.0
2	1	0.6097	0.7945	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	186.7	216.9	1000.0	1255.0
2	2	0.6087	0.4087	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	-0.0	-0.0	1000.0	1255.0
2	3	0.6965	0.5060	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	4	0.7670	0.3908	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	5	0.8188	0.2660	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	6	0.8502	0.1347	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	7	0.8609	-0.0000	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	8	0.8502	-0.1347	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	9	0.8188	-0.2660	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	10	0.7670	-0.3908	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	11	0.6965	-0.5060	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	12	0.6087	-0.6087	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
2	13	0.6097	-0.7945	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	146.7	-216.9	1000.0	1255.0
3	1	0.5007	0.8673	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	153.3	216.9	1000.0	1255.0
3	2	0.5060	0.6965	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	3	0.4999	0.4999	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	4	0.5879	0.3928	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	5	0.6532	0.2706	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	6	0.6934	0.1379	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	7	0.7071	0.0000	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	8	0.6934	-0.1379	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	9	0.6532	-0.2706	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	10	0.5879	-0.3928	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	11	0.4999	-0.4999	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	12	0.5060	-0.6965	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
3	13	0.5007	-0.8673	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	153.3	216.9	1000.0	1255.0
4	1	0.3832	0.9252	1.306	1.306	3997.8	358.03	0.24786	3903.6	3986.0	117.4	216.9	1000.0	1255.0
4	2	0.3908	0.7670	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
4	3	0.3928	0.5879	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
4	4	0.3826	0.3826	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0
4	5	0.4687	0.2706	1.100	1.100	3459.2	468.35	0.30026	4215.0	3499.2	0.0	0.0	1000.0	1255.0

Figure 14. (Continued)





SOLUTION SURFACE -				X =	0.0284	I:N	PLANE I	I	M	Q	P	RHO	T	(FT/SEC)	V	W	PT	H
I	J	Y	Z	(IN)	(IN)	(FT/SEC)	(LB/IN <sup>2</sup> )	(LB/FT <sup>3</sup> )	(DEG R)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(BTU/LBM)
12	10	-0.7670	-0.3908	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	-0.0	-0.0	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
12	11	-0.6965	-0.5060	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	-0.0	-0.0	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
12	12	-0.6087	-0.6087	1.100	3459.2	468.35	0.3002E 00	4215.0	3499.2	-0.0	-0.0	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
12	13	-0.6097	-0.7965	1.306	3997.8	558.02	0.2478E 00	3903.6	3986.0	-186.7	-243.3	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	1	-0.7781	0.7081	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-216.9	-216.9	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	2	-0.7745	0.6097	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-243.3	-243.3	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	3	-0.8673	0.5007	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-265.6	-265.6	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	4	-0.9252	0.3832	1.306	3997.8	558.02	0.2478E 00	3903.6	3986.0	-283.4	-283.4	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	5	-0.9673	0.2592	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-296.2	-296.2	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	6	-0.9929	0.1307	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-304.1	-304.1	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	7	-1.0015	0.0000	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-306.7	-306.7	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	8	-0.9929	-0.1307	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-304.1	-304.1	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	9	-0.9673	-0.2592	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-296.2	-296.2	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	10	-0.9252	-0.3832	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-283.4	-283.4	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	11	-0.8673	-0.5007	1.306	3997.8	558.02	0.2478E 00	3903.6	3986.0	-265.6	-265.6	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	12	-0.7965	-0.6097	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-243.3	-243.3	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0
13	13	-0.7081	-0.7081	1.306	3997.8	558.03	0.2478E 00	3903.6	3986.0	-216.9	-216.9	1000.0	1255.0	1255.0	0	-0.0	1000.0	1255.0

XSTEP REGULATING PARAMETERS

LIMITING POINT I = 1 AND J = 5 SAFETY FACTOR = 0.70400 DELTA X = 0.0870

Figure 14. (Continued)

SOLUTION SURFACE - X = 10.0000 (IN) PLANE 25

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA= 77.2662 (IN\*\*2) MASS FLOW RATE RATIO = 0.95720

XTHRUST = -5131.48 (LBF) YTHRUST = 80.70 (LBF) ZTHRUST = 136.73 (LBF)

XMOMT = 126.50 (FT-LBF) YMOMT = -172.27 (FT-LBF) ZMOMT = 485.01 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y	Z	M	Q	P	RHC	T	U	V	W	PT	H
		(IN)	(IN)		(FT/SEC)	(LBF/IN2)	(LBF/FT3)	(DEG R)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN2)	(BTU/LB/K)
1	1	3.2108	4.0661	3.985	6913.2	6.72	0.1448E-01	1253.7	6767.5	705.0	1223.5	1000.0	1255.0
1	2	3.5762	3.6734	4.027	6930.4	6.36	0.1329E-01	1233.9	6758.5	697.6	1366.4	1000.0	1255.0
1	3	3.7953	3.1531	4.076	6950.1	5.96	0.1329E-01	1211.1	6764.7	694.8	1435.3	1000.0	1255.0
1	4	3.9400	2.4758	4.098	6958.7	5.79	0.1301E-01	1201.1	6804.1	671.5	1294.9	1000.0	1255.0
1	5	3.9912	1.6896	4.090	6956.0	5.84	0.1310E-01	1204.2	6860.2	624.9	965.5	1000.0	1255.0
1	6	3.9997	0.8407	4.090	6955.8	5.84	0.1311E-01	1204.5	6909.8	606.1	515.3	1000.0	1255.0
1	7	4.0000	-0.0293	4.089	6955.1	5.86	0.1313E-01	1205.3	6928.5	606.3	42.6	1000.0	1255.0
1	8	3.9555	-0.8923	4.082	6952.5	5.91	0.1321E-01	1208.3	6917.0	576.5	-400.5	1000.0	1255.0
1	9	3.8284	-1.7383	4.075	6949.7	5.96	0.1330E-01	1211.5	6887.1	487.7	-792.8	1000.0	1255.0
1	10	3.6157	-2.5662	4.066	6946.1	6.03	0.1341E-01	1215.7	6844.5	347.1	-1131.3	1000.0	1255.0
1	11	3.3143	-3.3590	4.044	6937.3	6.21	0.1370E-01	1226.0	6792.4	163.6	-1400.5	1000.0	1255.0
1	12	2.9459	-4.0587	4.013	6925.0	6.47	0.1409E-01	1240.1	6747.6	-26.1	-1557.4	1000.0	1255.0
1	13	2.5385	-4.6337	3.968	6906.4	6.87	0.1471E-01	1261.6	6714.8	-186.9	-1604.4	1000.0	1255.0
2	1	2.7974	4.3716	3.953	6859.9	7.01	0.1493E-01	1269.1	6777.6	690.5	1093.2	1000.0	1255.0
2	2	2.9968	3.6765	4.364	7055.1	4.00	0.1017E-01	1088.5	6671.8	798.5	1384.1	1000.0	1255.0
2	3	3.3593	3.1401	4.375	7058.6	4.05	0.1008E-01	1084.5	6870.5	818.0	1396.8	1000.0	1255.0
2	4	3.5878	2.4914	4.336	7045.6	4.25	0.1044E-01	1099.7	6884.6	775.6	1281.2	1000.0	1255.0
2	5	3.6594	1.7490	4.291	7030.0	4.50	0.1088E-01	1118.0	6922.1	713.3	998.5	1000.0	1255.0
2	6	3.7391	0.8950	4.259	7018.8	4.69	0.1120E-01	1131.1	6965.7	669.5	542.5	1000.0	1255.0
2	7	3.7464	0.0300	4.247	7014.5	4.76	0.1132E-01	1136.2	6983.9	654.4	14.8	1000.0	1255.0
2	8	3.6848	-0.9526	4.245	7013.8	4.77	0.1135E-01	1137.0	6970.8	613.7	-473.4	1000.0	1255.0
2	9	3.5400	-1.8264	4.244	7013.4	4.78	0.1136E-01	1137.4	6937.8	517.2	-887.2	1000.0	1255.0
2	10	3.3023	-2.6476	4.250	7015.4	4.75	0.1130E-01	1135.2	6897.1	371.3	-1227.7	1000.0	1255.0
2	11	2.9657	-3.4275	4.254	7017.0	4.72	0.1125E-01	1133.2	6851.8	283.8	-1493.4	1000.0	1255.0
2	12	2.5519	-4.1145	4.245	7013.8	4.77	0.1134E-01	1136.9	6815.6	-3.8	-1655.7	1000.0	1255.0
2	13	2.1102	-5.0969	3.912	6882.5	7.41	0.1553E-01	1289.0	6694.7	-298.5	-1568.7	1000.0	1255.0
3	1	2.3047	4.6124	3.918	6835.0	7.35	0.1544E-01	1286.1	6784.4	623.0	993.3	1000.0	1255.0
3	2	2.5116	4.0853	4.303	7034.3	4.43	0.1076E-01	1113.0	6877.4	710.7	1295.5	1000.0	1255.0
3	3	2.6793	3.1900	4.766	7176.7	2.49	0.7134E-02	944.4	6958.5	668.4	1480.0	1000.0	1255.0
3	4	3.0720	2.5207	4.701	7158.7	2.70	0.7546E-02	965.9	6981.3	905.0	1299.5	1000.0	1255.0
3	5	3.2944	1.7416	4.592	7127.3	3.08	0.8299E-02	1003.3	7007.8	850.5	982.4	1000.0	1255.0
3	6	3.3924	0.8946	4.518	7104.7	3.38	0.8862E-02	1030.0	7040.4	787.7	538.3	1000.0	1255.0
3	7	3.4188	-0.0393	4.481	7093.1	3.54	0.9161E-02	1043.8	7054.1	742.4	-3.0	1000.0	1255.0
3	8	3.3433	-0.9811	4.481	7053.2	3.54	0.9159E-02	1043.7	7040.2	686.8	-526.4	1000.0	1255.0
3	9	3.1712	-1.8686	4.498	7098.5	3.46	0.9022E-02	1037.4	7006.9	585.7	-973.9	1000.0	1255.0
3	10	2.8796	-2.7318	4.540	7111.5	3.29	0.8692E-02	1022.1	6965.2	430.0	-1368.7	1000.0	1255.0
3	11	2.4660	-3.5137	4.607	7131.7	3.03	0.8191E-02	998.1	6924.7	252.1	-1686.9	1000.0	1255.0
3	12	2.0798	-4.6768	4.220	7004.7	4.93	0.1161E-01	1147.6	6791.5	-157.8	-1707.7	1000.0	1255.0
3	13	1.6587	-5.4596	3.849	6854.4	8.07	0.1651E-01	1321.1	6681.7	-362.7	-1485.7	1000.0	1255.0
4	1	1.7415	4.7942	3.882	6869.1	7.72	0.1599E-01	1304.3	6789.3	489.7	922.2	1000.0	1255.0
4	2	1.9430	4.3731	4.224	7006.0	4.91	0.1151E-01	1146.0	6801.9	576.0	1180.0	1000.0	1255.0
4	3	2.1164	3.7038	4.740	7169.7	2.57	0.7294E-02	952.8	6969.9	712.4	1522.1	1000.0	1255.0
4	4	2.2478	2.5557	5.190	7280.4	1.52	0.5004E-02	819.5	7086.7	900.4	1404.3	1000.0	1255.0
4	5	2.6794	1.7939	5.057	7250.2	1.77	0.5580E-02	856.1	7109.3	982.4	1029.0	1000.0	1255.0

Figure 14. (Continued)

SOLUTION SURFACE -														ε = 10.000C (IN)		PLANE 25											
I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN <sup>2</sup> )	RMC (LBF/FT <sup>3</sup> )	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN <sup>2</sup> )	H (BTU/LBM)														
4	6	2.8927	0.9281	4.924	7217.9	2.07	0.6238E-02	895.1	7133.1	949.8	560.3	1000.0	1255.0														
4	7	2.9649	-0.0426	4.858	7201.1	2.23	0.6594E-02	915.2	7145.2	895.8	-23.3	1000.0	1255.0														
4	8	2.8747	1.0246	4.875	7205.4	2.19	0.6501E-02	910.0	7130.7	837.6	-608.2	1000.0	1255.0														
4	9	2.6377	-1.9337	4.953	7225.2	2.00	0.6084E-02	886.2	7098.6	747.5	-1120.6	1000.0	1255.0														
4	10	2.2090	-2.7584	5.118	7264.1	1.65	0.5310E-02	839.2	7057.3	623.2	-1604.3	1000.0	1255.0														
4	11	1.9307	-4.1671	4.688	7155.1	2.74	0.7630E-02	970.2	6856.9	75.0	-1903.3	1000.0	1255.0														
4	12	1.5734	-5.1084	4.182	6950.6	5.18	0.1203E-01	1164.1	6782.8	-466.1	-1673.7	1000.0	1255.0														
4	13	1.1825	-5.7316	3.783	6824.4	8.83	0.1760E-01	1355.4	6671.3	-388.2	-1384.0	1000.0	1255.0														
5	1	1.1445	4.9153	3.867	6862.6	7.87	0.1622E-01	1311.7	6799.5	310.7	875.3	1000.0	1255.0														
5	2	1.3341	4.5608	4.163	6983.7	5.31	0.1224E-01	1172.1	6885.3	403.5	1096.2	1000.0	1255.0														
5	3	1.4527	4.0446	4.655	7145.7	2.95	0.7852E-02	981.4	6978.2	494.9	1455.0	1000.0	1255.0														
5	4	1.6065	3.1314	5.245	7292.3	1.43	0.4786E-02	805.0	7075.8	646.7	1632.9	1000.0	1255.0														
5	5	1.8143	1.7493	5.575	7357.6	0.94	0.3689E-02	725.4	7227.9	827.3	1098.4	1000.0	1255.0														
5	6	2.0829	0.9183	5.460	7335.9	1.12	0.4036E-02	752.0	7242.9	1016.0	568.1	1000.0	1255.0														
5	7	2.2294	-0.0391	5.383	7320.7	1.22	0.4289E-02	770.5	7248.5	1025.1	-42.1	1000.0	1255.0														
5	8	2.0856	-1.0069	5.442	7332.5	1.15	0.4092E-02	756.1	7238.1	965.7	-665.8	1000.0	1255.0														
5	9	1.6215	-1.8594	5.610	7363.8	0.95	0.3592E-02	717.8	7216.1	770.7	-1248.0	1000.0	1255.0														
5	10	1.5859	-3.4165	5.327	7309.4	1.30	0.4484E-02	784.3	7017.5	430.5	-1955.3	1000.0	1255.0														
5	11	1.3204	-4.6664	4.758	7174.6	2.52	0.7181E-02	946.9	6686.0	-41.2	-2013.6	1000.0	1255.0														
5	12	1.0613	-5.4049	4.141	6975.2	5.47	0.1250E-01	1181.9	6785.5	-279.6	-1591.5	1000.0	1255.0														
5	13	0.7086	-5.9049	3.773	6819.5	8.96	0.1776E-01	1360.9	6634.4	-369.3	-1293.1	1000.0	1255.0														
6	1	0.5324	4.9821	3.866	6822.3	7.88	0.1623E-01	1312.1	6808.9	105.3	647.1	1000.0	1255.0														
6	2	0.6617	4.6711	4.132	6971.8	5.53	0.1261E-01	1186.0	6692.2	178.0	1035.3	1000.0	1255.0														
6	3	0.7497	4.2312	4.586	7125.5	3.10	0.8342E-02	1005.4	6986.5	254.0	1377.3	1000.0	1255.0														
6	4	0.8549	3.4674	5.217	7286.2	1.47	0.4897E-02	812.5	7076.3	373.6	1695.6	1000.0	1255.0														
6	5	0.8293	2.3030	5.650	7371.0	0.91	0.3483E-02	709.0	7216.1	443.5	1436.5	1000.0	1255.0														
6	6	0.8648	0.8648	5.757	7389.5	0.82	0.3210E-02	686.2	7350.5	493.6	1575.6	1000.0	1255.0														
6	7	1.1713	-0.0302	5.731	7385.1	0.84	0.3274E-02	691.6	7352.9	667.9	-42.6	1000.0	1255.0														
6	8	0.8337	-0.9314	5.795	7395.8	0.78	0.3120E-02	678.4	7346.3	492.0	-677.1	1000.0	1255.0														
6	9	0.8690	-2.4412	5.781	7353.4	0.80	0.3154E-02	681.3	7194.3	393.9	-1658.4	1000.0	1255.0														
6	10	0.8591	-3.8551	5.553	7353.6	1.01	0.3752E-02	730.4	6992.1	241.7	-2264.3	1000.0	1255.0														
6	11	0.6821	-4.9793	4.822	7191.6	2.33	0.6803E-02	926.6	6896.1	-114.5	-2037.0	1000.0	1255.0														
6	12	0.4931	-5.5962	4.156	6931.1	5.36	0.1232E-01	1175.1	6807.4	-297.9	-1518.5	1000.0	1255.0														
6	13	0.2320	-5.9897	3.804	6834.0	8.58	0.1725E-01	1344.4	6712.8	-394.9	-1219.0	1000.0	1255.0														
7	1	-0.0879	4.9990	3.875	6866.2	7.79	0.1610E-01	1307.7	6814.0	-118.0	846.5	1000.0	1255.0														
7	2	-0.0654	4.7175	4.175	6969.4	5.38	0.1268E-01	1188.8	6894.1	-97.2	1017.0	1000.0	1255.0														
7	3	-0.0351	4.3122	4.573	7121.6	3.15	0.8438E-02	1010.0	6989.1	-69.1	1365.9	1000.0	1255.0														
7	4	-0.0102	3.5986	5.222	7287.4	1.46	0.4876E-02	811.0	7077.4	-29.0	1736.5	1000.0	1255.0														
7	5	0.0006	2.4956	5.669	7374.3	0.90	0.3433E-02	744.8	7211.7	-1.9	1540.3	1000.0	1255.0														
7	6	0.0007	1.2350	5.784	7394.0	0.79	0.3145E-02	680.6	7347.4	1.6	828.7	1000.0	1255.0														
7	7	-0.0003	-0.0272	5.807	7397.9	0.77	0.3091E-02	675.9	7347.7	-1.8	-43.1	1000.0	1255.0														
7	8	-0.0027	-1.3104	5.859	7406.2	0.73	0.2975E-02	665.6	7347.7	-10.9	-952.6	1000.0	1255.0														
7	9	-0.0089	-2.6642	5.911	7414.6	0.69	0.2861E-02	655.3	7182.8	-33.7	-1835.0	1000.0	1255.0														
7	10	-0.0265	-4.0371	5.729	7384.7	0.84	0.3279E-02	692.1	6976.8	-109.3	-2418.0	1000.0	1255.0														
7	11	-0.0949	-5.1265	4.946	7223.4	2.01	0.6124E-02	988.5	6901.6	-290.0	-2112.1	1000.0	1255.0														
7	12	-0.1776	-5.6757	4.238	7011.2	4.82	0.1142E-01	1140.0	6838.9	-381.9	-1486.6	1000.0	1255.0														
7	13	-0.2695	-5.9996	3.883	6869.5	7.71	0.1598E-01	1303.9	6751.5	-435.9	-1190.6	1000.0	1255.0														
8	1	-0.7108	4.9995	3.861	6859.9	7.94	0.1632E-01	1314.9	6799.7	-348.0	837.6	1000.0	1255.0														
8	2	-0.7960	4.7044	4.125	6969.4	5.58	0.1268E-01	1188.7	6881.2	-380.6	1037.6	1000.0	1255.0														
8	3	-0.8131	4.2646	4.603	7130.3	3.04	0.8224E-02	999.7	5975.0	-381.8	1430.2	1000.0	1255.0														
8	4	-0.8673	3.4763	5.236	7290.2	1.44	0.4824E-02	807.6	7068.6	-411.1	1735.7	1000.0	1255.0														
8	5	-0.8607	2.3041	5.649	7370.8	0.92	0.3486E-02	709.2	7214.1	-428.2	1449.7	1000.0	1255.0														
8	6	-0.8286	0.0440	5.756	7389.2	0.82	0.3214E-02	686.5	7350.7	-489.7	572.5	1000.0	1255.0														
8	7	-1.1734	-0.0327	5.742	7386.9	0.83	0.3247E-02	689.3	7351.8	-696.9	-56.6	1000.0	1255.0														

Figure 14. (Continued)

SOLUTION SURFACE - X = 10.0000 (IN) PLANE 25

I	J	V	Z	M	Q	P	RMC	T	U	V	A	P1	H
		(IN)	(IN)		(FT/SEC)	(LBF/IN2)	(LBF/FT3)	(DEG R)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN2)	(RTU/LBM)
8	8	-0.8390	-0.9348	5.817	7359.4	0.77	0.3069E-02	674.0	7149.0	-515.2	-691.7	1000.0	1255.0
8	9	-0.4056	-2.4643	5.892	7411.5	0.71	0.2902E-02	659.0	7188.3	-519.0	-1729.0	1000.0	1255.0
8	10	-0.9663	-3.2018	5.771	7351.9	0.80	0.3177E-02	693.3	6970.1	-547.4	-2399.6	1000.0	1255.0
8	11	-0.9374	-5.5076	5.076	7254.5	1.23	0.5496E-02	850.6	6881.1	-569.1	-2226.1	1000.0	1255.0
8	12	-0.9112	-5.5076	4.531	7043.7	4.28	0.1049E-01	1101.9	6855.2	-578.6	-1511.8	1000.0	1255.0
8	13	-0.6185	-5.9993	3.932	6891.1	7.21	0.1523E-01	1279.2	6765.2	-539.3	-1195.2	1000.0	1255.0
9	1	-1.3207	-4.9022	3.022	6842.3	8.37	0.1695E-01	1335.0	6765.2	-550.9	864.9	1000.0	1255.0
9	2	-1.4473	-4.5528	4.140	6974.9	5.48	0.1251E-01	1182.4	6856.7	-579.5	1133.8	1000.0	1255.0
9	3	-1.5805	-4.1165	4.684	7154.0	2.75	0.7657E-02	971.5	6954.6	-566.9	1578.4	1000.0	1255.0
9	4	-1.5016	-3.1488	5.255	7294.3	1.41	0.4750E-02	802.6	7065.4	-635.7	1697.8	1000.0	1255.0
9	5	-1.6050	-1.7493	5.557	7354.2	1.01	0.3742E-02	729.6	7228.1	-793.6	1599.5	1000.0	1255.0
9	6	-2.0763	0.3150	5.442	7332.5	1.15	0.4091E-02	756.1	7244.9	-990.2	544.8	1000.0	1255.0
9	7	-2.2371	-0.0510	5.411	7326.4	1.18	0.4192E-02	763.5	7249.9	-1052.3	-95.0	1000.0	1255.0
9	8	-2.1153	-1.0287	5.550	7352.9	1.02	0.3763E-02	731.2	7235.8	-1067.3	-754.0	1000.0	1255.0
9	9	-1.6597	-1.8429	5.747	7387.8	0.82	0.3234E-02	688.3	7209.6	-906.9	-1334.1	1000.0	1255.0
9	10	-1.7300	-3.5190	5.727	7384.5	0.84	0.3283E-02	692.4	6912.2	-843.1	-2282.2	1000.0	1255.0
9	11	-1.6771	-4.7034	5.228	7288.7	1.45	0.4852E-02	809.5	6833.0	-777.3	-2414.6	1000.0	1255.0
9	12	-1.6571	-5.6196	4.384	7061.7	4.00	0.9995E-02	1080.8	6828.8	-776.2	-1622.7	1000.0	1255.0
9	13	-1.4232	-5.3929	3.912	6882.2	7.41	0.1546E-01	1289.4	6739.1	-690.5	-1213.4	1000.0	1255.0
10	1	-1.9816	-4.3421	3.793	6829.1	2.71	0.1745E-01	1350.0	6728.3	-679.8	931.3	1000.0	1255.0
10	2	-1.9205	-4.5174	4.201	6997.8	5.06	0.1492E-01	1155.7	6843.4	-656.5	1306.2	1000.0	1255.0
10	3	-2.0867	-3.7837	4.772	7178.3	2.48	0.7098E-02	942.5	6945.4	-661.0	1686.7	1000.0	1255.0
10	4	-2.2131	-2.5648	5.160	7273.7	1.57	0.5129E-02	827.6	7084.0	-815.5	1435.1	1000.0	1255.0
10	5	-2.6429	1.7855	5.014	7239.9	1.86	0.5781E-02	868.6	7114.2	-894.3	1001.9	1000.0	1255.0
10	6	-2.8801	-0.8980	4.909	7214.1	2.10	0.6316E-02	899.5	7139.6	-916.5	479.2	1000.0	1255.0
10	7	-2.9820	-0.0391	4.893	7210.1	2.14	0.6401E-02	904.3	7147.5	-936.6	-148.4	1000.0	1255.0
10	8	-2.9358	-1.0941	4.993	7234.9	1.91	0.5887E-02	874.6	7121.6	-989.0	-805.3	1000.0	1255.0
10	9	-2.7630	-2.0291	5.211	7284.9	1.48	0.4921E-02	814.1	7071.1	-1052.2	-1400.9	1000.0	1255.0
10	10	-2.3660	-2.8636	5.499	7343.3	1.08	0.3915E-02	742.9	7614.5	-1036.0	-1909.8	1000.0	1255.0
10	11	-2.3436	-4.4778	5.304	7304.8	1.33	0.4565E-02	789.9	6803.2	-916.5	-2497.0	1000.0	1255.0
10	12	-2.2694	-5.4818	4.476	7091.6	3.56	0.9201E-02	1045.6	6794.5	-849.0	-1845.2	1000.0	1255.0
10	13	-2.0368	-5.7581	3.860	6859.6	7.95	0.1633E-01	1315.2	6692.2	-816.7	-1281.7	1000.0	1255.0
11	1	-2.3634	-4.8166	3.825	6843.5	0.34	0.1690E-01	1333.6	6719.1	-692.8	1098.7	1000.0	1255.0
11	2	-2.4713	-4.2436	4.314	7038.0	4.37	0.1066E-01	1108.6	6842.6	-657.6	1510.0	1000.0	1255.0
11	3	-2.6026	-3.2417	4.764	7176.1	2.50	0.7149E-02	945.2	6956.7	-738.5	1598.3	1000.0	1255.0
11	4	-2.9800	2.5256	4.674	7151.1	2.79	0.7725E-02	975.0	6987.0	-764.6	1317.0	1000.0	1255.0
11	5	-3.2272	1.6998	4.577	7122.8	3.14	0.8408E-02	1008.6	7023.4	-768.7	902.9	1000.0	1255.0
11	6	-3.3702	0.8230	4.519	7105.2	3.37	0.8851E-02	1029.5	7051.9	-768.7	403.5	1000.0	1255.0
11	7	-3.4365	-0.1370	4.512	7103.0	3.40	0.8907E-02	1032.1	7058.6	-770.1	-190.7	1000.0	1255.0
11	8	-3.4209	-1.1269	4.573	7121.4	3.15	0.8418E-02	1010.0	7029.0	-792.6	-825.7	1000.0	1255.0
11	9	-3.3546	-2.0795	4.699	7158.0	2.71	0.7563E-02	966.7	6963.8	-843.8	-1425.2	1000.0	1255.0
11	10	-3.1921	-2.9966	4.919	7216.6	2.08	0.6284E-02	896.5	6887.5	-928.7	-1944.1	1000.0	1255.0
11	11	-2.8665	-3.8166	5.169	7275.6	1.56	0.5093E-02	825.3	6826.2	-979.5	-2319.2	1000.0	1255.0
11	12	-2.7967	-5.1741	4.619	7135.2	2.98	0.8104E-02	993.9	6748.9	-846.6	-2155.9	1000.0	1255.0
11	13	-2.5890	-5.0568	3.860	6859.4	7.95	0.1633E-01	1315.4	6657.9	-818.6	-1433.2	1000.0	1255.0
12	1	-2.7549	-4.5948	3.900	6876.9	7.54	0.1512E-01	1295.4	6724.9	-629.0	1293.2	1000.0	1255.0
12	2	-2.8650	-3.7973	4.397	7068.2	3.93	0.9871E-02	1075.5	6651.0	-654.9	1601.9	1000.0	1255.0
12	3	-3.2152	1.1860	4.404	7068.3	3.90	0.9816E-02	1073.0	6873.3	-659.1	1511.3	1000.0	1255.0
12	4	-3.4600	2.4524	4.357	7052.8	4.14	0.1024E-01	1091.3	6671.5	-667.5	1244.7	1000.0	1255.0
12	5	-3.6237	1.6524	4.305	7034.9	4.42	0.1074E-01	1112.3	6950.3	-671.4	894.7	1000.0	1255.0
12	6	-3.7187	0.7745	4.273	7023.7	4.61	0.1102E-01	1125.4	6982.3	-671.4	359.5	1000.0	1255.0
12	7	-3.7872	-0.7745	4.278	7025.4	4.58	0.1101E-01	1123.4	6990.0	-668.9	-222.5	1000.0	1255.0
12	8	-3.7506	-1.1772	4.322	7040.9	4.32	0.1037E-01	1105.3	6956.6	-670.8	-856.0	1000.0	1255.0
12	9	-3.7278	-2.1568	4.403	7077.9	3.91	0.9878E-02	1073.5	6880.0	-693.9	-1467.5	1000.0	1255.0

Figure 14. (Continued)

SOLUTION SURFACE -       $\epsilon = 10.0000$  (IN)      PLANE 25

I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RMC (LBM/FT3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN2)	H (BTU/LBM)
12	10	-3.5606	-3.0800	4.524	7106.7	3.35	0.9812E-02	1027.7	6787.4	-739.5	-1972.1	1000.0	1255.0
12	11	-3.5037	-3.3349	4.666	7148.0	2.81	0.7778E-02	977.7	6723.7	-793.9	-2295.1	1000.0	1255.0
12	12	-3.2186	-4.6502	4.715	7162.6	2.65	0.7457E-02	961.3	6717.1	-835.4	-2342.0	1000.0	1255.0
13	1	-3.0269	-5.6671	3.884	6870.3	7.69	0.1595E-01	1302.9	6622.9	-647.8	-1688.6	1000.0	1255.0
13	2	-3.3793	3.7737	4.012	6924.4	6.48	0.1411E-01	1240.8	6737.7	-566.6	1492.8	1000.0	1255.0
13	3	-3.6198	2.1350	4.154	6964.4	5.67	0.1283E-01	1194.5	6757.7	-556.2	1589.5	1000.0	1255.0
13	4	-3.8012	2.3716	4.146	6977.3	5.43	0.1244E-01	1176.3	6795.0	-576.4	1489.4	1000.0	1255.0
13	5	-3.9205	1.5450	4.119	6966.9	5.63	0.1276E-01	1191.6	6897.0	-599.3	1189.1	1000.0	1255.0
13	6	-3.9854	0.6737	4.106	6961.8	5.73	0.1292E-01	1197.5	6929.3	-608.9	773.6	1000.0	1255.0
13	7	-4.0000	-0.2409	4.122	6967.9	5.61	0.1278E-01	1190.5	6936.0	-610.3	280.2	1000.0	1255.0
13	8	-3.9997	-1.1935	4.159	6982.3	5.34	0.1228E-01	1173.8	6901.6	-606.8	-273.4	1000.0	1255.0
13	9	-3.9950	-2.1748	4.216	7003.3	4.96	0.1165E-01	1159.3	6820.2	-605.2	-863.4	1000.0	1255.0
13	10	-3.9669	-3.1629	4.295	7031.3	4.48	0.1084E-01	1116.5	6706.3	-611.8	-1468.6	1000.0	1255.0
13	11	-3.8724	-4.1032	4.324	7041.7	4.31	0.1055E-01	1104.5	6583.5	-633.6	-2015.6	1000.0	1255.0
13	12	-3.6724	-4.8571	4.215	7002.7	4.97	0.1167E-01	1149.9	6553.1	-629.0	-2401.7	1000.0	1255.0
13	13	-3.3802	-5.3600	4.008	6922.6	6.52	0.1417E-01	1242.9	6582.7	-570.8	-2402.1	1000.0	1255.0
13	13									-572.1	-2064.6	1000.0	1255.0

XSTEP REGULATION PARAMETERS

LIMITING POINT I = 13 AND J = 8      SAFETY FACTOR = 1.06490      DELTA X = 1.0330

EXECUTION TIME 1192.6 SECS

Figure 14. (Continued)

## 7. SAMPLE CASE 7

Sample cases 7 and 8 are designed to illustrate the tape data storage and retrieval operations. The two nozzles are identical in all respects, with case 7 running one inch down the nozzle and writing the solution on tape, and case 8 restarting from the tape to continue the solution to the end of the nozzle. Thus, all data are identical except the parameters NSTART and XMAX. NSTART is set equal to 0 in case 7 to generate a data tape, and equal to 5 in case 8 in order to restart from plane 5 data stored on tape by case 7. XMAX is set equal to 1.0 in case 7 to generate the solution to that point in the nozzle, and then set equal to 10.0 in case 8 to complete the solution.

The problem being considered is a skewed, uniform inlet flow into an axisymmetric,  $10^\circ$  conical nozzle 10 inches long having a throat radius of 1.0 inch, a throat radius of curvature of 0.5 inch, and the throat located at  $X = 0.0$ . Thus, in NAMELIST CNTRL, IVSTYP = 1, NP = 7, XMAX = 1.0, and NSTART = 0. PRINT1, PRINT2 and ERROR are allowed to assume their default values.

In NAMELIST WALSBL, the default values of NSYMMY, YAXIS, ZAXIS, XT, and RT are employed. RC is set equal to 0.5. Since the contour is a  $10^\circ$  cone, THETAT = THETA = 10.0. In order to completely specify the entire nozzle, XE = 10.0 even though the solution will proceed only to XMAX = 1.0. For a conical nozzle, RE does not need to be specified. The remaining parameters are concerned with super-elliptical contours and do not need to be specified here.

The gas thermodynamic properties are chosen to be those of a thermally and calorically perfect gas typical of solid propellant rocket motor exhaust products. Thus, GAMMA = 1.2 and RGAS = 60.0. No other parameters need to be specified for this option.

In a uniform flow skewed with respect to the nozzle contour, only one plane of symmetry will exist. The skewed flow is obtained in this example by specifying a uniform initial-value surface with a Mach number of 1.10 which has a pitch angle of  $-1.0^\circ$  superimposed on the entire surface. Such a flow will be symmetrical about the y-axis. If a uniform yaw angle is superimposed on the flow, the z-axis will be a plane of symmetry. However, the program logic for considering planes of symmetry always fixes the positive y-axis as one of the planes of symmetry. Thus, in order to take advantage of the flow symmetry, the skew angle must be selected as the pitch angle. Thus, NPVS = 1, and XIVS, YCIVS and ZCIVS are left at their default values. Also, MCIVS = 1.10, PTCIVS = 1000.0, and HCIVS = 1255.0 as in sample case 1. To specify the skew angle, THECIV = -1.0. The remaining parameters are not required in this problem. Thus, the specification of NAMELIST IVSL is complete.

Figure 15 presents the data deck for case 7. Figure 16 presents selected portions of the computer output. The solution required 13 planes to reach a nozzle length of one inch. This case required 166 seconds of central processor time and 89 seconds of peripheral processor time on the CDC 6500, and 309 seconds of central memory time on the IBM 7094.

SAMPLE CASE NO. 7  
\$CNTRL      IVSTYP=1,  
NP=7,  
XMAX=1.0,  
NSTART=0      \$  
\$WALSBL      RC=0.5,  
THETAT=10.0,  
XE=10.0,  
THETA=10.0      \$  
\$AROSBL      GAMMA=1.2,  
RGAS=60.0      \$  
\$IVSL      NPOS=1,  
MCVS=1.10,  
PTCIVS=1000.0,  
HCIVS=1255.0,  
THECIV=-1.0      \$

Figure 15. Data Deck 7

# THREE-DIMENSIONAL ANALYSIS OF SUPERSONIC NOZZLE FLOW

## ABSTRACT

THIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERSITY JET PROPULSION CENTER BY V. H. RANSOP AS A PART OF THE REQUIREMENTS OF AF CONTRACT NUMBER F33615-67-C-1068. THE CONTRACT WAS SPONSORED BY THE AERD PROPULSION LABORATORY WRIGHT PATTERSON AFB, OHIO AND PRINCIPAL INVESTIGATORS FOR PURDUE UNIVERSITY WERE PROFESSORS M. DOYLE THOMPSON AND JOE C. HOFFMAN. THE EQUATIONS OF MOTION FOR A THREE-DIMENSIONAL SUPERSONIC FLOW ARE SOLVED USING A NUMERICAL METHOD OF CHARACTERISTICS HAVING SECOND-ORDER ACCURACY. THE FLOW VARIABLES MUST BE SPECIFIED OVER A SPACE-LIKE INITIAL VALUE SURFACE WHICH ADJOINS THE NOZZLE BOUNDARIES. THE NOZZLE GEOMETRY IS SPECIFIED BY MEANS OF THE SUBROUTINE WALSUB. THE NOZZLE MAY HAVE PLANES OF SYMMETRY AND THE THERMODYNAMIC PROPERTIES OF THE GAS ARE DETERMINED BY MEANS OF THE SUBROUTINE ARDSUB.

## MAJOR ASSUMPTIONS

THE GASDYNAMIC MODEL IS BASED ON THE FOLLOWING ASSUMPTIONS. 1. CONTINUUM, 2. INVISCID, 3. STEADY, 4. STRICTLY ADIABATIC, 5. FROZEN OR EQUILIBRIUM CHEMICAL COMPOSITION, AND 6. SPECIFIED INITIAL DATA AND BOUNDARIES.

## JOB TITLE

SAMPLE CASE NO. 7

## THERMODYNAMIC MODEL

A CALORICALLY AND THERMALLY PERFECT GAS IS SPECIFIED AND IS CHARACTERIZED BY THE FOLLOWING VALUES  
SPECIFIC HEAT RATIO = 1.20000 AND GAS CONSTANT = 60.00000 (FT-LBF/LBM-DEG R)

## FLOW GEOMETRY

THE FLOW HAS 1 PLANES OF SYMMETRY PASSING THROUGH THE POINT-  
X = 0. (IN) Y = 0. (IN) Z = 0. (IN)  
THE COMPONENTS OF THE OUTER NORMAL ARE-  
NX1 = 0. NY1 = 0. NZ1 = -1.000000

Figure 16. Sample Case 7 Output

## NOZZLE GEOMETRY

ASYMMETRIC CIRCLE-LINE CONICAL NOZZLE HAVING THE FOLLOWING PARAMETERS

 $AT = 1.0000 \text{ (IN)}$      $RC = 0.5000 \text{ (IN)}$      $XE = 10.0000 \text{ (IN)}$      $ALPHA = 10.0000 \text{ (DEG)}$ 

## TYPE OF INITIAL DATA SURFACE

THE FOLLOWING VALUES ARE CONSTANT OVER THE ENTIRE INITIAL DATA SURFACE LOCATED AT  $X = 0. \text{ (IN)}$ 
 $M = 1.1000$      $THETA = -1.00 \text{ (DEG)}$      $PHI = 0. \text{ (DEG)}$      $ST = 1000.00 \text{ (LB*FT**2)}$      $\mu = 1255.00 \text{ (BTU/LBM)}$ 

Figure 16. (Continued)

INITIAL DATA - X = 0. (IN)

THRUST PARAMETERS

CROSS SECTION AREA = 1.5663 (IN\*\*2) MASS FLOW = 14.1553 (LBM/SEC)  
XTHRUST = -1934.95 (LBF) YTHRUST = 20.00 (LBF) ZTHRUST = -0. (LBF)  
XCMOT = -8.48 (FT-LBF) YCMOT = -820.03 (FT-LBF) ZCMOT = -0.00 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHC (LBM/FT3)	T IDEG RI	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN2)	M (BTU/LBM)
1	1	0.7071	0.7071	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
1	2	0.7933	0.6087	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
1	3	0.8660	0.5000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
1	4	0.9238	0.3827	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
1	5	0.9659	0.2588	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
1	6	0.9934	0.1305	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
1	7	1.0000	0.	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
2	1	0.6087	0.7933	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
2	2	0.6088	0.8660	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
2	3	0.6965	0.5000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
2	4	0.7671	0.3908	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
2	5	0.8188	0.2660	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
2	6	0.8503	0.1347	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
2	7	0.8609	0.	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
3	1	0.5000	0.8660	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
3	2	0.5060	0.6965	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
3	3	0.5000	0.5000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
3	4	0.5879	0.3928	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
3	5	0.6533	0.2706	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
3	6	0.6935	0.1379	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
3	7	0.7071	0.	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
4	1	0.3827	0.9278	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
4	2	0.3508	0.7671	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
4	3	0.3928	0.5879	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
4	4	0.3827	0.3827	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
4	5	0.4687	0.2706	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
4	6	0.5228	0.1401	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
4	7	0.5412	0.	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
5	1	0.2588	0.9659	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
5	2	0.2660	0.8188	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
5	3	0.2706	0.6533	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
5	4	0.2706	0.4687	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
5	5	0.2588	0.2588	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
5	6	0.3382	0.1401	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
5	7	0.3660	0.	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
6	1	0.1305	0.9934	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
6	2	0.1347	0.8503	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
6	3	0.1379	0.6935	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
6	4	0.1401	0.5228	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
6	5	0.1401	0.3382	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
6	6	0.1305	0.1305	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
6	7	0.1846	0.	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
7	1	0.0000	1.0000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0
7	2	0.0000	0.8609	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.	1000.0	1255.0



SOLUTION SURFACE - X = 0.0369 (IN) PLANE 1  
 THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)  
 CROSS SECTION AREA = 1.5706 (IN\*\*2) MASS FLOW RATE RATIO = 1.00462  
 XTHRUST = -1939.62 (LBF) YTHRUST = 18.64 (LBF) ZTHRUST = -7.01 (LBF)  
 XMOM = -8.43 (FT-LBF) YMOM = -817.44 (FT-LBF) ZMOM = -0.72 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN2)	RHO (LBM/FT3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PT (LBF/IN2)	M (BTU/LBM)
1	1	0.7078	0.7084	1.306	3026.4	308.62	0.4025E 00	2317.4	3017.9	134.9	180.5	1000.0	1255.0
1	2	0.7942	0.6099	1.310	3033.6	306.72	0.4008E 00	2315.5	3025.2	160.5	158.5	1000.0	1255.0
1	3	0.8631	0.5009	1.313	3039.7	305.11	0.3994E 00	2313.9	3031.4	182.7	132.1	1000.0	1255.0
1	4	0.9251	0.3834	1.315	3044.6	303.83	0.3982E 00	2312.6	3036.3	200.8	103.2	1000.0	1255.0
1	5	0.9672	0.2753	1.317	3048.2	302.90	0.3975E 00	2311.7	3039.9	214.1	69.7	1000.0	1255.0
1	6	0.9928	0.1708	1.318	3050.3	302.34	0.3970E 00	2311.1	3042.0	222.3	35.3	1000.0	1255.0
1	7	1.0014	0.0700	1.319	3051.1	302.15	0.3969E 00	2310.9	3042.8	225.1	-0.0	1000.0	1255.0
2	1	0.6092	0.7947	1.302	3018.1	300.80	0.4043E 00	2319.6	3009.7	103.6	198.5	1000.0	1255.0
2	2	0.6081	0.6088	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
2	3	0.6959	0.5060	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
2	4	0.7664	0.3908	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
2	5	0.8181	0.2760	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
2	6	0.8497	0.1734	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
2	7	0.8603	0.0700	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
3	1	0.5002	0.8675	1.297	3008.9	393.21	0.4064E 00	2321.9	3000.5	76.5	212.1	1000.0	1255.0
3	2	0.5054	0.6965	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
3	3	0.4994	0.5000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
3	4	0.5873	0.3928	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
3	5	0.6526	0.2706	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
3	6	0.6929	0.1739	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
3	7	0.7065	0.0700	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
4	1	0.3827	0.9254	1.292	2959.1	395.80	0.4087E 00	2324.5	2990.7	45.4	220.6	1000.0	1255.0
4	2	0.3902	0.7671	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
4	3	0.3922	0.5879	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
4	4	0.3820	0.3927	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
4	5	0.4680	0.2706	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
4	6	0.5221	0.1401	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
4	7	0.5409	0.0700	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
5	1	0.2258	0.9674	1.287	2958.8	340.55	0.4110E 00	2327.2	2980.3	14.2	224.4	1000.0	1255.0
5	2	0.2654	0.8188	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
5	3	0.2699	0.6533	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
5	4	0.2700	0.4497	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
5	5	0.2582	0.2758	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
5	6	0.3375	0.1401	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
5	7	0.3654	0.0700	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
6	1	0.1301	0.9929	1.282	2978.1	401.39	0.4135E 00	2329.9	2969.6	-16.4	223.7	1000.0	1255.0
6	2	0.1140	0.8503	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
6	3	0.1373	0.6935	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
6	4	0.1394	0.5228	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
6	5	0.1394	0.3382	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
6	6	0.1299	0.1303	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
6	7	0.1837	-0.0000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0
7	1	-0.0006	1.5014	1.276	2967.2	404.29	0.4159E 00	2337.7	2958.7	-45.9	210.9	1000.0	1255.0
7	2	-0.0006	0.8609	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	1000.0	1255.0

Figure 16. (Continued)

Figure 16. (Continued)

SOLUTION SURFACE - X = 0.2559 (IN) PLANE 5  
 THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)  
 CROSS SECTION AREA = 1.6657 (IN\*\*2) MASS FLOW RATE RATIO = 0.99902  
 XTPR(IST) = -1975.33 (LBF) YTHRUST = 13.79 (LBF) ZTHRUST = -67.68 (LBF)  
 XNCHT = -6.96 (FT-LBF) YNCHT = -839.34 (FT-LBF) ZNCHT = -1.65 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	X	Y	Z	M	Q	P	RNG	T	U	V	W	PT	H
		(IN)	(IN)	(IN)		(FT/SEC)	(LBF/IN2)	(LBF/FT3)	(DEG N)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN2)	(BTU/LBM)
1	1	0.7320	0.7351	1.519	3432.2	287.80	0.3134E 00	2204.3	3380.0	407.8	435.0	435.0	1000.0	1255.0
1	2	0.7320	0.5329	1.523	3440.2	285.95	0.3117E 00	2201.9	3387.9	453.3	377.4	377.4	1000.0	1255.0
1	3	0.7320	0.5200	1.526	3445.8	284.64	0.3105E 00	2200.2	3393.5	509.9	313.5	313.5	1000.0	1255.0
1	4	0.7320	0.3983	1.526	3450.0	283.87	0.3096E 00	2198.0	3400.9	548.3	241.7	241.7	1000.0	1255.0
1	5	0.7320	0.2694	1.526	3453.4	282.90	0.3089E 00	2197.4	3402.9	576.9	163.9	163.9	1000.0	1255.0
1	6	0.7320	0.1359	1.512	3455.4	282.45	0.3085E 00	2197.2	3403.3	594.4	82.0	82.0	1000.0	1255.0
1	7	0.7320	0.0000	1.512	3455.8	282.33	0.3084E 00	2197.2	3403.3	600.1	0.0	0.0	1000.0	1255.0
2	1	0.6296	0.5245	1.515	3424.2	289.65	0.3150E 00	2206.6	3372.1	345.3	484.5	484.5	1000.0	1255.0
2	2	0.6296	0.6711	1.412	3231.2	336.17	0.3567E 00	2262.1	3201.5	292.6	325.0	325.0	1000.0	1255.0
2	3	0.6296	0.5163	1.415	3237.9	334.51	0.3552E 00	2260.2	3208.5	338.9	272.9	272.9	1000.0	1255.0
2	4	0.6296	0.3989	1.418	3244.1	332.98	0.3536E 00	2258.5	3215.0	377.1	213.0	213.0	1000.0	1255.0
2	5	0.6296	0.2715	1.420	3247.6	332.11	0.3531E 00	2257.5	3218.7	406.9	145.5	145.5	1000.0	1255.0
2	6	0.6296	0.1374	1.420	3247.5	332.12	0.3531E 00	2257.5	3218.5	427.3	72.2	72.2	1000.0	1255.0
2	7	0.6296	0.0000	1.419	3248.3	332.43	0.3534E 00	2257.9	3217.0	434.7	0.0	0.0	1000.0	1255.0
3	1	0.5128	0.8997	1.511	3416.2	291.06	0.3163E 00	2209.4	3366.2	277.6	525.0	525.0	1000.0	1255.0
3	2	0.5128	0.7104	1.409	3226.3	337.39	0.3577E 00	2232.4	3196.5	235.8	368.2	368.2	1000.0	1255.0
3	3	0.5128	0.5030	1.277	2975.1	402.18	0.4145E 00	2330.7	2964.6	115.0	134.1	134.1	1000.0	1255.0
3	4	0.5128	0.3953	1.280	2975.1	400.72	0.4128E 00	2329.2	2970.9	137.7	108.9	108.9	1000.0	1255.0
3	5	0.5128	0.2724	1.283	2980.6	400.62	0.4128E 00	2329.2	2977.1	146.3	76.9	76.9	1000.0	1255.0
3	6	0.5128	0.1387	1.282	2977.8	401.45	0.4135E 00	2330.0	2974.0	151.0	37.1	37.1	1000.0	1255.0
3	7	0.5128	0.0000	1.282	2977.8	401.45	0.4135E 00	2330.0	2974.0	151.0	0.0	0.0	1000.0	1255.0
4	1	0.3846	0.9594	1.508	3412.4	292.41	0.3175E 00	2210.1	3360.5	204.7	556.5	556.5	1000.0	1255.0
4	2	0.3846	0.7822	1.408	3247.7	337.78	0.3581E 00	2263.9	3195.1	170.0	401.8	401.8	1000.0	1255.0
4	3	0.3846	0.5913	1.277	2967.6	404.17	0.4158E 00	2332.6	2962.8	68.4	154.9	154.9	1000.0	1255.0
4	4	0.3846	0.3834	1.165	2741.2	465.75	0.4680E 00	2388.4	2740.8	2.7	47.1	47.1	1000.0	1255.0
4	5	0.3846	0.2711	1.168	2746.0	464.43	0.4669E 00	2387.3	2745.7	12.1	34.7	34.7	1000.0	1255.0
4	6	0.3846	0.1403	1.169	2748.9	463.63	0.4662E 00	2386.6	2748.8	21.5	14.9	14.9	1000.0	1255.0
4	7	0.3846	0.0000	1.168	2746.2	464.39	0.4669E 00	2387.2	2746.1	24.1	0.1	0.1	1000.0	1255.0
5	1	0.2658	1.0028	1.504	3464.5	294.26	0.3192E 00	2212.4	3352.7	126.5	577.5	577.5	1000.0	1255.0
5	2	0.2658	0.8349	1.405	3219.4	339.11	0.3593E 00	2265.4	3189.6	100.3	425.6	425.6	1000.0	1255.0
5	3	0.2658	0.5570	1.276	2967.0	404.33	0.4160E 00	2332.8	2961.9	32.8	170.9	170.9	1000.0	1255.0
5	4	0.2658	0.4695	1.165	2741.3	465.73	0.4680E 00	2388.4	2740.7	-9.7	55.7	55.7	1000.0	1255.0
5	5	0.2658	0.2589	1.115	2635.5	495.22	0.4926E 00	2412.9	2635.2	-36.0	9.2	9.2	1000.0	1255.0
5	6	0.2658	0.1401	1.116	2638.2	494.45	0.4919E 00	2412.3	2638.0	-33.3	6.4	6.4	1000.0	1255.0
5	7	0.2658	0.0000	1.115	2637.0	494.79	0.4922E 00	2412.6	2636.8	-31.5	0.0	0.0	1000.0	1255.0
6	1	0.1325	1.3289	1.498	3354.6	296.59	0.3213E 00	2215.3	3342.9	56.2	587.5	587.5	1000.0	1255.0
6	2	0.1325	1.0372	1.400	3269.2	341.67	0.3615E 00	2268.2	3178.8	28.4	439.4	439.4	1000.0	1255.0
6	3	0.1325	0.5975	1.272	2958.5	406.59	0.4179E 00	2334.9	2953.0	-7.3	181.1	181.1	1000.0	1255.0
6	4	0.1325	0.5237	1.164	2739.3	466.29	0.4685E 00	2388.9	2738.4	-25.5	62.8	62.8	1000.0	1255.0
6	5	0.1325	0.3383	1.115	2636.1	495.04	0.4924E 00	2412.8	2635.8	-38.8	11.3	11.3	1000.0	1255.0
6	6	0.1325	0.1305	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-42.5	0.0	0.0	1000.0	1255.0
6	7	0.1325	0.0000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-42.5	0.0	0.0	1000.0	1255.0
7	1	-0.0030	1.3374	1.494	3385.8	298.56	0.3232E 00	2217.9	3334.3	-27.5	587.8	587.8	1000.0	1255.0
7	2	-0.0039	0.8775	1.395	3159.5	344.09	0.3637E 00	2270.9	3168.9	-37.7	439.9	439.9	1000.0	1255.0

Figure 15. (Continued)



SOLUTION SURFACE - X = 1.0000 (IN) PLANE 13

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA = 2.1390 (IN\*\*2) MASS FLOW RATE RATIO = 0.9319

XTHRUST = -2095.61 (LBF) YTHRUST = -0.56 (LBF) ZTHRUST = -150.65 (LBF)

XCMOT = 1.08 (FT-LBF) YCMOT = -890.53 (FT-LBF) ZCMOT = -12.50 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y	Z	M	Q	P	RMC	T	U	V	W	PT	H
		(IN)	(IN)		(FT/SEC)	(LBF/IN2)	(LBF/FT3)	(DEG K)	(FT/SEC)	(FT/SEC)	(FT/SEC)		(BTU/LBM)
1	1	0.8239		1.670	3702.4	228.46	0.2585E 00	2121.0	3646.1	457.8	451.4	1000.0	1255.0
1	2	0.9252		0.7139	3705.3	227.87	0.2579E 00	2120.1	3649.0	511.5	390.3	1000.0	1255.0
1	3	1.0108		0.5865	3705.7	227.78	0.2579E 00	2120.0	3649.4	556.2	320.1	1000.0	1255.0
1	4	1.0790		0.4487	3705.8	227.75	0.2578E 00	2119.9	3649.5	596.2	242.4	1000.0	1255.0
1	5	1.1286		0.3033	3707.1	227.48	0.2576E 00	2119.5	3650.8	623.4	160.5	1000.0	1255.0
1	6	1.1586		0.1529	3709.2	227.06	0.2572E 00	2118.9	3652.8	639.2	79.4	1000.0	1255.0
1	7	1.1686		0.0000	3710.2	226.85	0.2570E 00	2118.5	3653.9	644.3	C.C	1000.0	1255.0
2	1	0.7056		0.7125	3702.8	228.38	0.2584E 00	2120.9	3650.4	440.4	504.8	1000.0	1255.0
2	2	0.8087		0.5920	3705.9	227.73	0.2578E 00	2119.9	3653.5	503.8	437.1	1000.0	1255.0
2	3	0.8918		0.4574	3705.8	227.75	0.2578E 00	2119.9	3653.4	554.9	279.4	1000.0	1255.0
2	4	0.9523		0.3122	3706.9	227.53	0.2576E 00	2119.6	3654.3	593.1	189.1	1000.0	1255.0
2	5	0.9895		0.1585	3709.4	227.01	0.2571E 00	2118.8	3656.6	616.4	96.3	1000.0	1255.0
2	6	0.7754		0.3139	3705.4	226.56	0.2567E 00	2118.1	3658.5	625.5	C.C	1000.0	1255.0
2	7	1.0022		0.2000	3711.6	231.22	0.2611E 00	2125.3	3633.0	326.6	551.2	1000.0	1255.0
3	1	0.5807		1.0141	3689.1	229.87	0.2598E 00	2123.2	3643.3	366.5	459.6	1000.0	1255.0
3	2	0.5849		0.8152	3655.6	229.87	0.2598E 00	2123.2	3643.3	432.3	436.5	1000.0	1255.0
3	3	0.5715		0.5811	3720.9	229.87	0.2598E 00	2115.1	3669.8	312.6	339.4	1000.0	1255.0
3	4	0.6743		0.4567	3724.4	229.94	0.2594E 00	2114.0	3673.3	512.6	339.4	1000.0	1255.0
3	5	0.7504		0.3139	3725.4	229.73	0.2594E 00	2113.6	3674.3	570.4	231.1	1000.0	1255.0
3	6	0.7973		0.1604	3727.8	229.23	0.2593E 00	2112.9	3676.3	606.2	118.6	1000.0	1255.0
3	7	0.8133		0.0001	3730.5	229.70	0.2591E 00	2112.0	3678.5	620.7	0.1	1000.0	1255.0
4	1	0.4627		1.0815	3682.3	232.63	0.2624E 00	2127.4	3626.4	249.2	588.5	1000.0	1255.0
4	2	0.4694		0.8974	3686.2	231.82	0.2617E 00	2126.2	3634.2	281.0	545.3	1000.0	1255.0
4	3	0.4465		0.6835	3712.6	228.36	0.2605E 00	2117.8	3661.7	333.7	513.7	1000.0	1255.0
4	4	0.4316		0.4427	3716.9	228.47	0.2597E 00	2116.4	3676.4	381.6	392.1	1000.0	1255.0
4	5	0.5314		0.3131	3719.9	228.85	0.2591E 00	2115.4	3679.6	471.4	276.3	1000.0	1255.0
4	6	0.5941		0.1621	3721.5	228.53	0.2588E 00	2114.9	3681.2	526.5	145.3	1000.0	1255.0
4	7	0.6156		0.0000	3723.3	228.15	0.2584E 00	2114.3	3682.9	547.6	C.C	1000.0	1255.0
5	1	0.2975		1.1301	3676.7	233.79	0.2635E 00	2129.2	3620.9	167.6	616.0	1000.0	1255.0
5	2	0.3036		0.9371	3678.9	233.34	0.2631E 00	2128.5	3626.9	190.1	586.2	1000.0	1255.0
5	3	0.3039		0.7589	3702.7	228.40	0.2598E 00	2120.9	3632.3	224.3	568.3	1000.0	1255.0
5	4	0.3021		0.5723	3708.7	228.16	0.2597E 00	2119.0	3668.2	264.8	478.5	1000.0	1255.0
5	5	0.2847		0.2968	3674.7	234.21	0.2639E 00	2129.8	3653.9	268.1	283.4	1000.0	1255.0
5	6	0.2760		0.1608	3677.3	233.68	0.2634E 00	2129.0	3656.8	356.7	151.7	1000.0	1255.0
5	7	0.4080		0.0000	3678.8	233.35	0.2631E 00	2128.5	3658.3	388.0	C.C	1000.0	1255.0
6	1	0.1473		1.1593	3611.7	234.84	0.2645E 00	2130.8	3615.9	66.7	631.7	1000.0	1255.0
6	2	0.1499		0.9933	3612.9	234.60	0.2643E 00	2130.4	3620.9	97.4	607.8	1000.0	1255.0
6	3	0.1503		0.8050	3695.2	229.95	0.2599E 00	2123.3	3644.9	112.2	597.3	1000.0	1255.0
6	4	0.1510		0.6043	3659.8	228.98	0.2590E 00	2121.8	3659.5	133.8	528.1	1000.0	1255.0
6	5	0.1488		0.3879	3667.7	235.69	0.2653E 00	2132.1	3646.5	136.1	365.5	1000.0	1255.0
6	6	0.1161		0.1486	3678.9	243.91	0.2730E 00	2144.3	3623.7	127.4	144.9	1000.0	1255.0
6	7	0.1978		-0.2000	3631.1	243.44	0.2726E 00	2143.6	3626.2	187.7	-0.0	1000.0	1255.0
7	1	-0.0052		1.1666	3666.2	236.01	0.2656E 00	2132.6	3610.4	7.3	636.7	1000.0	1255.0
7	2	-0.0077		1.0049	3666.6	235.93	0.2655E 00	2132.4	3614.8	2.6	614.1	1000.0	1255.0

Figure 16. (Continued)



## 8. SAMPLE CASE 8

The purpose of this sample case is to demonstrate the tape restart capability of the program. A tape was created by sample case 7, with 13 solution planes. That solution can be continued from any plane including or after plane 3. For example, `NSTART = 5` in `NAMelist CNTRLl` will initiate the solution for plane 6. The only change required to the data deck of case 7 is the change of `NSTART` to 5 and the increase of `XMAX` to 10.0.

Figure 17 illustrates the data deck for case 8. Figure 18 presents selected portions of the computer output. As seen by cross-checking, planes 5 through 13 are identical to those calculated in case 7. This sample case required 418 seconds of central processor time and 194 seconds of peripheral processor time on the CDC 6500, and 873 seconds of central memory time on the IBM 7094.

SAMPLE CASE NO. 8  
\$CNTRL      IVSTYP=1,  
NP=7,  
XMAX=10.0,  
NSTART=5      \$  
\$WALSBL      RC=0.5,  
THETAT=10.0,  
XE=10.0,  
THETA E=10.0      \$  
\$AROSBL      GAMMA=1.2,  
RGAS=60.0      \$  
\$IVSL      NPOS=1,  
MCIVS=1.10,  
PTCIVS=1000.0,  
HCIVS=1255.0,  
THECIV=-1.0      \$

Figure 17. Data Deck 8

SOLUTION SURFACE - C = 0.2555 (IN) PLANE 5  
 THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)  
 CROSS SECTION AREA- 1.6857 (IN\*\*2) MASS FLOW RATE RATIO = 0.99902  
 XTHRUST = -1975.03 (LBF) YTHRUST = 13.79 (LBF) ZTHRUST = -67.68 (LBF)  
 XACMT = -6.96 (FT-LBF) YACMT = -839.34 (FT-LBF) ZACMT = -1.65 (FT-LBF)  
 BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	U	Z	H	Q	P	RHC	T	U	V	W	PI	M
(IN)	(IN)	(FT/SEC)	(LBF/IN2)	(LBF/FT3)	(LBF/IN2)	(LBF/IN2)	(LBF/IN2)	(LBF/IN2)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN2)	(BTU/LBM)
1	1	0.7370	0.7351	1.519	3432.2	297.80	0.3134F	00	3380.0	407.8	435.0	1000.0	1255.0
1	2	0.8219	0.6329	1.523	3440.2	295.94	0.3117L	00	3387.9	463.5	377.4	1000.0	1255.0
1	3	0.4977	0.5200	1.524	3465.8	284.64	0.3105F	00	3393.5	509.9	313.5	1000.0	1255.0
1	4	0.9579	0.3983	1.526	3450.0	283.67	0.3096F	00	3397.6	548.3	241.7	1000.0	1255.0
1	5	1.0018	0.2694	1.530	3453.4	282.90	0.3089F	00	3400.9	576.9	163.5	1000.0	1255.0
1	6	1.0285	0.1359	1.532	3455.4	282.45	0.3085F	00	3402.9	594.4	82.0	1000.0	1255.0
1	7	1.0374	-0.0000	1.532	3455.8	282.33	0.3084F	00	3403.3	600.1	0.0	1000.0	1255.0
2	1	0.6296	0.8245	1.515	3424.2	289.65	0.3150F	00	3372.1	345.3	484.5	1000.0	1255.0
2	2	0.6174	0.6211	1.512	3331.2	336.17	0.3557F	00	3201.5	292.6	325.0	1000.0	1255.0
2	3	0.7068	0.5163	1.415	3237.9	332.51	0.3557F	00	3208.5	338.9	272.9	1000.0	1255.0
2	4	0.7789	0.3989	1.418	3244.1	332.98	0.3538F	00	3215.0	371.1	213.0	1000.0	1255.0
2	5	0.8318	0.2715	1.420	3247.6	332.11	0.3531F	00	3218.7	404.9	145.4	1000.0	1255.0
2	6	0.8640	0.1374	1.420	3247.5	332.12	0.3531F	00	3218.5	427.3	72.2	1000.0	1255.0
2	7	0.8750	-0.0000	1.420	3246.3	332.43	0.3534F	00	3217.9	434.7	0.3	1000.0	1255.0
3	1	0.5164	0.8997	1.511	3418.2	291.06	0.3163F	00	3366.2	277.6	525.0	1000.0	1255.0
3	2	0.5128	0.7104	1.409	3226.3	337.39	0.3577F	00	3263.4	318.5	368.2	1000.0	1255.0
3	3	0.4987	0.5030	1.277	2969.1	403.78	0.4155F	00	2964.6	92.6	134.1	1000.0	1255.0
3	4	0.5871	0.3953	1.280	2775.1	402.18	0.4141C	00	2970.9	114.0	108.9	1000.0	1255.0
3	5	0.6528	0.2724	1.283	2780.6	400.72	0.4129F	00	2976.6	132.1	76.9	1000.0	1255.0
3	6	0.6934	0.1387	1.283	2981.0	400.62	0.4128F	00	2977.1	142.3	37.1	1000.0	1255.0
3	7	0.7071	0.0000	1.282	2977.8	401.45	0.4135F	00	2974.0	151.0	0.3	1000.0	1255.0
4	1	0.3946	0.9594	1.508	3412.4	292.41	0.3175F	00	3360.5	204.7	556.5	1000.0	1255.0
4	2	0.3950	0.7822	1.277	3224.7	337.78	0.3581F	00	3195.1	170.0	401.8	1000.0	1255.0
4	3	0.3910	0.5913	1.277	2967.6	404.17	0.4158F	00	2942.8	66.4	154.5	1000.0	1255.0
4	4	0.3790	0.3834	1.165	2741.2	465.75	0.4680F	00	2740.8	2.7	47.1	1000.0	1255.0
4	5	0.3651	0.2711	1.168	2746.0	464.43	0.4680F	00	2745.7	12.1	34.7	1000.0	1255.0
4	6	0.3194	0.1403	1.169	2748.9	463.63	0.4662L	00	2748.8	21.5	14.9	1000.0	1255.0
4	7	0.3374	0.0000	1.168	2746.7	464.39	0.4669F	00	2746.1	24.1	0.1	1000.0	1255.0
5	1	0.2658	1.504	1.504	3404.5	294.26	0.3192F	00	3352.7	128.5	577.5	1000.0	1255.0
5	2	0.2673	0.8369	1.405	3219.4	339.11	0.3593F	00	3189.6	100.3	425.6	1000.0	1255.0
5	3	0.2681	0.6570	1.276	2967.0	404.33	0.4160F	00	2961.9	32.8	170.9	1000.0	1255.0
5	4	0.2667	0.4695	1.165	2741.3	465.73	0.4680F	00	2740.7	9.7	55.7	1000.0	1255.0
5	5	0.2545	0.2589	1.115	2635.5	495.22	0.4926F	00	2635.2	-36.0	6.4	1000.0	1255.0
5	6	0.3338	0.1401	1.116	2638.2	494.45	0.4919F	00	2638.0	-31.3	0.0	1000.0	1255.0
5	7	0.3617	0.0000	1.115	2637.0	494.79	0.4922F	00	2636.8	-31.5	0.0	1000.0	1255.0
6	1	0.1325	1.0289	1.498	3354.6	276.59	0.3213F	00	3342.9	50.2	587.9	1000.0	1255.0
6	2	0.1332	0.8669	1.400	3209.2	361.67	0.3615F	00	3178.8	28.4	435.4	1000.0	1255.0
6	3	0.1347	0.6975	1.272	2958.5	466.29	0.4179F	00	2953.0	-7.3	101.1	1000.0	1255.0
6	4	0.1359	0.5237	1.164	2739.3	466.29	0.4685F	00	2736.4	-29.5	62.8	1000.0	1255.0
6	5	0.1357	0.3383	1.115	2631.1	495.04	0.4924F	00	2631.8	-38.8	11.3	1000.0	1255.0
6	6	0.1261	0.1305	1.100	2604.4	503.93	0.4998F	00	2604.0	-45.5	0.0	1000.0	1255.0
6	7	0.1801	0.0000	1.100	2604.4	503.93	0.4998F	00	2604.0	-45.5	0.0	1000.0	1255.0
7	1	-0.0030	1.0374	1.494	3385.8	298.66	0.3232F	00	3334.3	-27.5	587.8	1000.0	1255.0
7	2	-0.0039	0.8775	1.395	3159.5	344.09	0.3637F	00	3168.9	-27.7	435.6	1000.0	1255.0

Figure 18. Sample Case 8 Output

SOLUTION SURFACE -										X = 0.2559 (IN) PLANE 5										XSTEP REGULATION PARAMETERS										
I	J	Y	Z	M	Q	P	RHO	F	U	V	M	OF	M	U	V	M	OF	M	U	V	M	OF	M	U	V	M	OF	M	U	V
1	3	-0.0043	0.7111	1.267	2948.1	409.39	0.4203E 00	2337.6	2942.1	-42.9	182.6	100.0	182.6	2942.1	-42.9	182.6	100.0	182.6	2942.1	-42.9	182.6	100.0	182.6	2942.1	-42.9	182.6	100.0	182.6	2942.1	-42.9
7	4	-0.0044	C-5.422	1.16:	2732.4	468.20	0.4701E 00	2330.5	2731.1	-44.2	63.3	100.0	63.3	2731.1	-44.2	63.3	100.0	63.3	2731.1	-44.2	63.3	100.0	63.3	2731.1	-44.2	63.3	100.0	63.3	2731.1	-44.2
7	5	-0.0045	C-3.661	1.113	2632.4	496.08	0.4933E 00	2413.8	2632.0	-45.1	12.6	100.0	12.6	2632.0	-45.1	12.6	100.0	12.6	2632.0	-45.1	12.6	100.0	12.6	2632.0	-45.1	12.6	100.0	12.6	2632.0	-45.1
7	6	-0.0045	0.1846	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	100.0	0.0	2604.0	-45.5	0.0	100.0	0.0	2604.0	-45.5	0.0	100.0	0.0	2604.0	-45.5	0.0	100.0	0.0	2604.0	-45.5
7	7	-0.0045	0.3000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-45.5	0.0	100.0	0.0	2604.0	-45.5	0.0	100.0	0.0	2604.0	-45.5	0.0	100.0	0.0	2604.0	-45.5	0.0	100.0	0.0	2604.0	-45.5
8	1	-0.1384	1.0281	1.491	3380.4	299.93	0.3243E 00	2219.5	3379.0	-104.1	578.3	100.0	578.3	3379.0	-104.1	578.3	100.0	578.3	3379.0	-104.1	578.3	100.0	578.3	3379.0	-104.1	578.3	100.0	578.3	3379.0	-104.1
8	2	-0.1407	0.8665	1.393	3196.2	344.92	0.3644E 00	2271.8	3165.7	-102.1	428.8	100.0	428.8	3165.7	-102.1	428.8	100.0	428.8	3165.7	-102.1	428.8	100.0	428.8	3165.7	-102.1	428.8	100.0	428.8	3165.7	-102.1
8	3	-0.1429	0.5974	1.266	2945.8	409.99	0.4208E 00	2338.2	2939.4	-77.0	178.1	100.0	178.1	2939.4	-77.0	178.1	100.0	178.1	2939.4	-77.0	178.1	100.0	178.1	2939.4	-77.0	178.1	100.0	178.1	2939.4	-77.0
8	4	-0.1447	0.5237	1.161	2731.8	468.37	0.4702E 00	2390.6	2730.5	-77.9	66.8	100.0	66.8	2730.5	-77.9	66.8	100.0	66.8	2730.5	-77.9	66.8	100.0	66.8	2730.5	-77.9	66.8	100.0	66.8	2730.5	-77.9
8	5	-0.1446	C-3.323	1.113	2631.7	496.27	0.4934E 00	2413.8	2631.2	-76.7	10.3	100.0	10.3	2631.2	-76.7	10.3	100.0	10.3	2631.2	-76.7	10.3	100.0	10.3	2631.2	-76.7	10.3	100.0	10.3	2631.2	-76.7
8	6	-0.1350	0.1305	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-75.0	0.0	100.0	0.0	2604.0	-75.0	0.0	100.0	0.0	2604.0	-75.0	0.0	100.0	0.0	2604.0	-75.0	0.0	100.0	0.0	2604.0	-75.0
8	7	-0.1891	0.3000	1.100	2604.4	503.93	0.4998E 00	2420.0	2604.0	-75.0	0.0	100.0	0.0	2604.0	-75.0	0.0	100.0	0.0	2604.0	-75.0	0.0	100.0	0.0	2604.0	-75.0	0.0	100.0	0.0	2604.0	-75.0
9	1	-0.2715	1.0013	1.489	3376.6	300.84	0.3751E 00	2270.6	3375.2	-179.2	558.5	100.0	558.5	3375.2	-179.2	558.5	100.0	558.5	3375.2	-179.2	558.5	100.0	558.5	3375.2	-179.2	558.5	100.0	558.5	3375.2	-179.2
9	2	-0.2747	C-8.339	1.392	3193.6	345.58	0.3650E 00	2272.5	3163.3	-168.5	434.6	100.0	434.6	3163.3	-168.5	434.6	100.0	434.6	3163.3	-168.5	434.6	100.0	434.6	3163.3	-168.5	434.6	100.0	434.6	3163.3	-168.5
9	3	-0.2765	0.5568	1.264	2941.9	411.05	0.4217E 00	2339.2	2935.1	-113.6	163.7	100.0	163.7	2935.1	-113.6	163.7	100.0	163.7	2935.1	-113.6	163.7	100.0	163.7	2935.1	-113.6	163.7	100.0	163.7	2935.1	-113.6
9	4	-0.2755	0.5694	1.158	2726.8	469.74	0.4714E 00	2391.8	2725.3	-135.3	51.7	100.0	51.7	2725.3	-135.3	51.7	100.0	51.7	2725.3	-135.3	51.7	100.0	51.7	2725.3	-135.3	51.7	100.0	51.7	2725.3	-135.3
9	5	-0.2734	0.2589	1.112	2628.7	497.11	0.4944E 00	2414.5	2628.2	-52.8	7.7	100.0	7.7	2628.2	-52.8	7.7	100.0	7.7	2628.2	-52.8	7.7	100.0	7.7	2628.2	-52.8	7.7	100.0	7.7	2628.2	-52.8
9	6	-0.3427	C-1.401	1.117	2629.3	497.94	0.4944E 00	2414.5	2628.8	-54.7	5.3	100.0	5.3	2628.8	-54.7	5.3	100.0	5.3	2628.8	-54.7	5.3	100.0	5.3	2628.8	-54.7	5.3	100.0	5.3	2628.8	-54.7
9	7	-0.3706	0.3000	1.111	2627.5	497.45	0.4944E 00	2414.5	2626.9	-55.5	0.0	100.0	0.0	2626.9	-55.5	0.0	100.0	0.0	2626.9	-55.5	0.0	100.0	0.0	2626.9	-55.5	0.0	100.0	0.0	2626.9	-55.5
10	1	-0.3998	0.3573	1.485	3370.3	302.32	0.3265E 00	2272.4	3319.0	-248.9	530.3	100.0	530.3	3319.0	-248.9	530.3	100.0	530.3	3319.0	-248.9	530.3	100.0	530.3	3319.0	-248.9	530.3	100.0	530.3	3319.0	-248.9
10	2	-0.4019	0.7609	1.388	3186.2	347.43	0.3666E 00	2274.5	3159.0	-228.6	373.7	100.0	373.7	3159.0	-228.6	373.7	100.0	373.7	3159.0	-228.6	373.7	100.0	373.7	3159.0	-228.6	373.7	100.0	373.7	3159.0	-228.6
10	3	-0.3994	0.5911	1.255	2932.6	413.53	0.4234E 00	2341.5	2925.5	-143.5	144.9	100.0	144.9	2925.5	-143.5	144.9	100.0	144.9	2925.5	-143.5	144.9	100.0	144.9	2925.5	-143.5	144.9	100.0	144.9	2925.5	-143.5
10	4	-0.3877	0.1833	1.156	2721.2	471.31	0.4727E 00	2393.1	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9
10	5	-0.4739	0.7711	1.156	2721.2	471.31	0.4727E 00	2393.1	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9
10	6	-0.5280	0.1403	1.156	2721.2	471.31	0.4727E 00	2393.1	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9	41.9	100.0	41.9	2719.5	-85.9
10	7	-0.5210	0.3000	1.154	2717.3	472.38	0.4736E 00	2394.0	2715.4	-101.7	0.0	100.0	0.0	2715.4	-101.7	0.0	100.0	0.0	2715.4	-101.7	0.0	100.0	0.0	2715.4	-101.7	0.0	100.0	0.0	2715.4	-101.7
11	1	-0.5192	0.7049	1.382	3175.5	350.15	0.3690E 00	2277.5	3109.3	-282.7	336.6	100.0	336.6	3109.3	-282.7	336.6	100.0	336.6	3109.3	-282.7	336.6	100.0	336.6	3109.3	-282.7	336.6	100.0	336.6	3109.3	-282.7
11	2	-0.5030	0.5027	1.255	2914.6	415.69	0.4257E 00	2343.7	2917.3	-165.5	123.5	100.0	123.5	2917.3	-165.5	123.5	100.0	123.5	2917.3	-165.5	123.5	100.0	123.5	2917.3	-165.5	123.5	100.0	123.5	2917.3	-165.5
11	3	-0.4953	C-3.951	1.254	2913.0	415.69	0.4257E 00	2343.7	2917.3	-165.5	123.5	100.0	123.5	2917.3	-165.5	123.5	100.0	123.5	2917.3	-165.5	123.5	100.0	123.5	2917.3	-165.5	123.5	100.0	123.5	2917.3	-165.5
11	4	-0.6009	0.2722	1.253	2919.2	417.13	0.4258E 00	2343.7	2916.4	-199.7	69.9	100.0	69.9	2916.4	-199.7	69.9	100.0	69.9	2916.4	-199.7	69.9	100.0	69.9	2916.4	-199.7	69.9	100.0	69.9	2916.4	-199.7
11	5	-0.7015	0.1386	1.253	2919.2	417.13	0.4258E 00	2343.7	2916.4	-199.7	69.9	100.0	69.9	2916.4	-199.7	69.9	100.0	69.9	2916.4	-199.7	69.9	100.0	69.9	2916.4	-199.7	69.9	100.0	69.9	2916.4	-199.7
11	6	-0.7151	0.0000	1.250	2914.2	418.48	0.4281E 00	2346.2	2906.4	-210.4	32.8	100.0	32.8	2906.4	-210.4	32.8	100.0	32.8	2906.4	-210.4	32.8	100.0	32.8	2906.4	-210.4	32.8	100.0	32.8	2906.4	-210.4
11	7	-0.6334	C-4.216	1.474	3349.9	307.19	0.3309E 00	2278.3	3299.0	-312.5	493.1	100.0	493.1	3299.0	-312.5	493.1	100.0	493.1	3299.0	-312.5	493.1	100.0	493.1	3299.0	-312.5	493.1	100.0	493.1	3299.0	-312.5
12	1	-0.6235	0.6197	1.378	3167.1	352.26	0.3708E 00	2279.8	3164.9	-328.1	293.3	100.0	293.3	3164.9	-328.1	293.3	100.0	293.3	3164.9	-328.1	293.3	100.0	293.3	3164.9	-328.1	293.3	100.0	293.3	3164.9	-328.1
12	2	-0.7125	0.5153	1.377	3163.9	352.07	0.3715E 00	2280.6	3133.3	-365.6	243.1	100.0	243.1	3133.3	-365.6	243.1	100.0	243.1	3133.3	-365.6	243.1	100.0	243.1	3133.3	-365.6	243.1	100.0	243.1	3133.3	-365.6
12	3	-0.7841	C-3.978	1.377	3163.9	352.07	0.3715E 00	2280.6	3133.3	-365.6	243.1	100.0	243.1	3133.3	-365.6	243.1	100.0	243.1	3133.3	-365.6	243.1	100.0	243.1	3133.3	-365.6	243.1	100.0	243.1	3133.3	-365.6
12	4	-0.8367	C-2.704	1.374	3163.0	353.31	0.3718E 00	2280.9	3132.7	-418.5	185.6	100.0	185.6	3132.7	-418.5	185.6	100.0	185.6	3132.7	-418.5	185.6	100.0	185.6	3132.7	-418.5	185.6	100.0	185.6	3132.7	-418.5
12	5	-0.8690	0.1366	1.373	3156.8	354.89	0.3718E 00	2282.6	3126.2	-434.3	59.4	100.0	59.4	3126.2	-434.3	59.4	100.0	59.4	3126.2	-434.3</										

SOLUTION SURFACE - X = 0.3079 (IN) PLANE 6

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

CROSS SECTION AREA = 1.7156 (IN\*\*2) MASS FLOW RATE RATIO = 0.99708

XTHRUST = -1983.51 (LBF) YTHRUST = 12.67 (LBF) ZTHRUST = -80.60 (LBF)

XMCHT = -6.64 (FT-LBF) YMCHT = -843.84 (FT-LBF) ZMCHT = -1.87 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	X (IN)	Y (IN)	Z (IN)	M	Q (FT/SEC)	P (LBF/IN**2)	RHC (LBF/FT**3)	T (DEG R)	U (FT/SEC)	V (FT/SEC)	W (FT/SEC)	PI (1/IN**2)	M (BTU/LBF)
1	1	0.7183	0.7417	1.518	3430.2	288.25	0.3138E 00	2204.8	3378.1	409.7	437.7	1000.0	1255.0	
1	2	0.8291	0.6387	1.522	3437.5	286.56	0.3122E 00	2202.7	3385.3	464.1	375.7	1000.0	1255.0	
1	3	0.9055	0.5248	1.525	3444.3	284.99	0.3108E 00	2200.7	3392.0	516.5	311.5	1000.0	1255.0	
1	4	0.9663	0.4019	1.528	3449.4	283.82	0.3097E 00	2199.1	3397.0	549.2	239.3	1000.0	1255.0	
1	5	1.0106	0.2719	1.530	3452.1	283.19	0.3092E 00	2198.3	3399.7	577.2	167.1	1000.0	1255.0	
1	6	1.0376	0.1331	1.530	3452.7	283.06	0.3091E 00	2198.2	3400.2	594.0	81.2	1000.0	1255.0	
1	7	1.0466	-0.0000	1.530	3452.8	283.03	0.3090E 00	2198.1	3400.4	599.6	0.0	1000.0	1255.0	
2	1	0.6349	0.8320	1.515	3424.2	289.65	0.3150E 00	2206.6	3372.2	348.0	482.4	1000.0	1255.0	
2	2	0.6725	0.6267	1.449	3302.3	318.68	0.3411E 00	2242.0	3264.6	336.6	366.4	1000.0	1255.0	
2	3	0.7127	0.5209	1.453	3308.8	317.09	0.3397E 00	2240.1	3271.4	390.7	306.4	1000.0	1255.0	
2	4	0.7854	0.4025	1.456	3315.5	315.47	0.3383E 00	2238.2	3278.3	434.1	238.6	1000.0	1255.0	
2	5	0.8187	0.2740	1.458	3319.4	314.53	0.3374E 00	2237.1	3282.3	466.3	165.6	1000.0	1255.0	
2	6	0.8713	0.1387	1.458	3319.9	314.42	0.3373E 00	2237.0	3282.6	489.1	83.3	1000.0	1255.0	
2	7	0.8824	-0.0000	1.458	3318.4	314.77	0.3376E 00	2237.4	3281.0	497.0	0.2	1000.0	1255.0	
3	1	0.5207	0.9078	1.512	3420.0	290.64	0.3159E 00	2207.9	3368.0	286.6	523.7	1000.0	1255.0	
3	2	0.5169	0.7167	1.447	3298.0	319.73	0.3421E 00	2243.2	3260.3	271.4	416.5	1000.0	1255.0	
3	3	0.5008	0.5058	1.330	3074.1	376.15	0.3917E 00	2304.8	3064.7	148.9	148.2	1000.0	1255.0	
3	4	0.5896	0.3975	1.334	3080.4	374.51	0.3903E 00	2303.2	3071.4	180.7	150.8	1000.0	1255.0	
3	5	0.6558	0.2739	1.336	3085.9	373.07	0.3890E 00	2301.7	3077.2	206.9	104.5	1000.0	1255.0	
3	6	0.6966	0.1395	1.337	3087.2	372.75	0.3887E 00	2301.4	3078.5	224.2	53.1	1000.0	1255.0	
3	7	0.7104	0.0000	1.336	3084.5	373.44	0.3893E 00	2302.1	3075.9	230.1	0.3	1000.0	1255.0	
4	1	0.3977	0.9681	1.509	3414.8	291.85	0.3170E 00	2209.4	3362.9	206.7	556.1	1000.0	1255.0	
4	2	0.3926	0.7945	1.329	3072.1	376.65	0.3921E 00	2305.3	3062.4	110.1	219.0	1000.0	1255.0	
4	3	0.3794	0.5846	1.213	2839.0	438.87	0.4454E 00	2366.8	2837.4	41.6	64.3	1000.0	1255.0	
4	4	0.4658	0.2720	1.216	2845.1	437.19	0.4440E 00	2363.3	2843.9	60.1	61.2	1000.0	1255.0	
4	5	0.5203	0.1407	1.217	2848.2	436.35	0.4433E 00	2362.6	2847.1	74.6	24.4	1000.0	1255.0	
4	6	0.5388	0.0000	1.217	2846.4	436.83	0.4437E 00	2363.0	2845.3	78.1	0.2	1000.0	1255.0	
5	1	0.2678	1.0317	1.505	3406.9	293.69	0.3187E 00	2211.7	3355.1	131.0	577.3	1000.0	1255.0	
5	2	0.2691	0.8422	1.442	3289.8	371.71	0.3638E 00	2245.6	3252.2	123.3	480.7	1000.0	1255.0	
5	3	0.2689	0.6606	1.328	3069.8	377.26	0.3926E 00	2306.0	3059.6	62.5	242.0	1000.0	1255.0	
5	4	0.2668	0.4710	1.213	2838.8	438.91	0.4456E 00	2364.9	2836.9	18.2	101.5	1000.0	1255.0	
5	5	0.2540	0.2593	1.145	2659.1	477.44	0.4788E 00	2398.3	2698.9	-16.6	21.5	1000.0	1255.0	
5	6	0.2334	0.1404	1.147	2703.7	476.17	0.4767E 00	2397.2	2703.6	-7.5	17.6	1000.0	1255.0	
5	7	0.2000	0.0000	1.147	2703.4	476.23	0.4768E 00	2397.3	2703.4	-3.5	0.0	1000.0	1255.0	
6	1	0.1333	1.0381	1.500	3396.9	296.05	0.3208E 00	2214.7	3345.2	53.1	587.5	1000.0	1255.0	
6	2	0.1337	0.8745	1.437	3279.9	374.14	0.3640E 00	2248.4	3241.9	43.0	496.2	1000.0	1255.0	
6	3	0.1344	0.7013	1.324	3061.7	379.36	0.3955E 00	2308.1	3051.0	10.7	255.3	1000.0	1255.0	
6	4	0.1355	0.5254	1.211	2825.5	439.83	0.4462E 00	2365.7	2833.2	-13.8	113.5	1000.0	1255.0	
6	5	0.1351	0.3387	1.145	2698.6	477.59	0.4774E 00	2398.4	2698.2	-26.7	35.7	1000.0	1255.0	
6	6	0.1252	0.1306	1.110	2625.8	497.92	0.4948E 00	2415.1	2625.5	-39.1	6.0	1000.0	1255.0	
6	7	0.1793	0.0000	1.111	2628.2	497.76	0.4943E 00	2414.6	2628.0	-36.1	0.0	1000.0	1255.0	
7	1	-0.0035	1.0466	1.495	3368.6	298.00	0.3226E 00	2217.1	3337.0	24.8	588.3	1000.0	1255.0	
7	2	-0.0044	0.8651	1.432	3270.0	376.58	0.3482E 00	2251.2	3231.7	-35.0	497.5	1000.0	1255.0	

Figure 18. (Continued)



SOLUTION SURFACE - K = 10.0000 (IN) PLANE 33

THRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL MASS FLOW RATE)

MASS SECTION AREA = 11.8932 (IN\*\*2) MASS FLOW RATE RATIO = 0.99737

XTHRUST = -2532.85 (LBF) YTHRUST = 6.41 (LBF) ZTHRUST = -170.34 (LBF)

XCMOM = -10.05 (FT-LBF) YCMOM = 1377.43 (FT-LBF) ZCMOM = 77.55 (FT-LBF)

BOUNDARY AND INTERIOR FLOW PARAMETERS

I	J	Y	Z	M	Q	P	RHL	T	U	V	W	W1	M
		(IN)	(IN)		(FT/SEC)	(LBF/IN**2)	(LBF/FT**2)	(DEG R)	(FT/SEC)	(FT/SEC)	(FT/SEC)	(LBF/IN**2)	(LBTU/LBM)
1	1	1.9514	1.9395	3.081	5532.1	18.22	0.3143E-01	1391.6	5448.1	675.4	663.2	1000.0	1255.0
1	2	2.1919	1.6699	3.081	5532.2	18.22	0.3142E-01	1391.6	5448.2	759.8	581.5	1000.0	1255.0
1	3	2.3099	1.3716	3.082	5532.6	18.21	0.3141E-01	1391.4	5448.5	830.6	482.9	1000.0	1255.0
1	4	2.5478	1.0497	3.082	5532.8	18.20	0.3139E-01	1391.3	5448.8	886.5	370.3	1000.0	1255.0
1	5	2.8626	0.7098	3.082	5532.9	18.20	0.3138E-01	1391.3	5448.8	927.3	251.2	1000.0	1255.0
1	6	2.7327	0.3581	3.082	5532.7	18.20	0.3140E-01	1391.4	5448.7	952.3	127.3	1000.0	1255.0
1	7	2.7556	0.0000	3.082	5532.7	18.20	0.3140E-01	1391.4	5448.6	960.7	0.0	1000.0	1255.0
2	1	1.6498	2.1766	3.081	5532.2	18.22	0.3142E-01	1391.6	5448.2	579.2	766.5	1000.0	1255.0
2	2	1.6819	1.6672	3.075	5526.9	18.42	0.3172E-01	1394.1	5469.0	551.7	570.8	1000.0	1255.0
2	3	1.9204	1.1847	3.076	5527.0	18.42	0.3171E-01	1394.1	5469.2	640.7	474.7	1000.0	1255.0
2	4	2.1100	0.8697	3.076	5527.3	18.41	0.3169E-01	1393.9	5469.6	701.8	366.5	1000.0	1255.0
2	5	2.2524	0.7293	3.076	5527.5	18.40	0.3168E-01	1393.9	5469.7	751.0	249.1	1000.0	1255.0
2	6	2.3587	0.5100	3.076	5527.4	18.40	0.3167E-01	1393.9	5469.6	787.4	126.4	1000.0	1255.0
2	7	2.3698	0.2000	3.076	5527.3	18.41	0.3169E-01	1393.9	5469.3	798.9	0.0	1000.0	1255.0
3	1	1.3726	2.3778	3.082	5532.7	18.20	0.3140E-01	1391.4	5448.6	473.3	836.2	1000.0	1255.0
3	2	1.4070	1.9096	3.076	5527.1	18.41	0.3170E-01	1394.0	5469.1	480.5	652.8	1000.0	1255.0
3	3	1.3750	1.3676	3.074	5525.2	18.49	0.3180E-01	1394.9	5490.2	420.5	448.8	1000.0	1255.0
3	4	1.6114	1.0722	3.074	5525.2	18.49	0.3181E-01	1395.0	5490.4	501.5	352.2	1000.0	1255.0
3	5	1.7906	0.7372	3.074	5525.4	18.48	0.3180E-01	1394.9	5490.7	568.4	243.0	1000.0	1255.0
3	6	1.9004	0.3760	3.074	5525.2	18.49	0.3180E-01	1394.9	5490.5	606.2	123.2	1000.0	1255.0
3	7	1.9402	0.0001	3.073	5525.0	18.49	0.3182E-01	1395.0	5490.0	620.5	0.0	1000.0	1255.0
4	1	1.0706	2.5391	3.082	5532.7	18.18	0.3137E-01	1391.1	5449.1	360.0	891.0	1000.0	1255.0
4	2	1.0859	2.1047	3.076	5527.8	18.39	0.3166E-01	1393.7	5469.6	351.5	718.6	1000.0	1255.0
4	3	1.0825	1.6105	3.074	5525.9	18.46	0.3177E-01	1394.6	5490.6	333.0	527.1	1000.0	1255.0
4	4	1.0593	1.0546	3.079	5530.1	18.30	0.3154E-01	1392.6	5511.4	309.5	332.2	1000.0	1255.0
5	1	2.9133	0.7442	3.078	5529.6	18.32	0.3157E-01	1392.9	5511.3	383.7	234.5	1000.0	1255.0
5	2	1.6415	0.3451	3.078	5529.3	18.33	0.3158E-01	1393.0	5511.1	432.4	120.4	1000.0	1255.0
5	3	1.4949	0.0001	3.078	5529.0	18.34	0.3160E-01	1393.1	5510.6	450.2	0.0	1000.0	1255.0
5	4	0.7290	2.6574	3.083	5533.5	18.17	0.3135E-01	1391.0	5449.5	240.1	930.5	1000.0	1255.0
5	5	0.7418	2.2502	3.077	5528.4	18.36	0.3143E-01	1393.4	5479.1	231.2	766.6	1000.0	1255.0
5	6	0.7477	1.7912	3.076	5527.1	18.42	0.3170E-01	1394.0	5491.5	223.6	505.3	1000.0	1255.0
5	7	0.7923	1.2924	3.080	5531.5	18.25	0.3147E-01	1391.9	5512.5	212.8	406.1	1000.0	1255.0
6	1	0.7119	0.7177	3.081	5541.5	17.87	0.3093E-01	1387.1	5533.6	197.5	220.9	1000.0	1255.0
6	2	0.9476	0.3867	3.090	5540.4	17.92	0.3094E-01	1387.7	5532.8	264.7	119.1	1000.0	1255.0
6	3	0.9188	0.0000	3.090	5539.9	17.94	0.3102E-01	1387.9	5532.3	289.7	0.0	1000.0	1255.0
6	4	0.3747	2.7300	3.083	5533.8	18.16	0.3134E-01	1390.9	5449.7	116.0	954.0	1000.0	1255.0
6	5	0.3825	2.3391	3.078	5528.9	18.35	0.3161E-01	1393.2	5470.3	110.7	794.8	1000.0	1255.0
6	6	0.3854	1.9011	3.077	5527.9	18.39	0.3166E-01	1393.7	5491.9	103.9	620.8	1000.0	1255.0
6	7	0.3937	1.4426	3.082	5533.1	18.19	0.3130E-01	1391.2	5514.6	99.3	453.2	1000.0	1255.0
6	8	0.3932	0.9386	3.094	5543.7	17.79	0.3081E-01	1386.1	5535.4	97.0	288.5	1000.0	1255.0
6	9	0.3697	0.3641	3.105	5553.9	17.42	0.3027E-01	1381.2	5552.1	89.8	112.1	1000.0	1255.0
6	10	0.5202	-0.0000	3.104	5552.7	17.46	0.3033E-01	1381.8	5551.1	135.0	-0.0	1000.0	1255.0
7	1	0.0149	2.7555	3.083	5534.0	18.15	0.3133E-01	1390.7	5449.9	-9.8	961.0	1000.0	1255.0
7	2	0.0112	2.1606	3.078	5529.2	18.33	0.3159E-01	1393.0	5470.6	-14.2	803.2	1000.0	1255.0

Figure 18. (Continued)

SOLUTION SURFACE - K 10.0000 (IN) PLANE 33

I	J	(IN)	Z	M	Q	P	RHC	Y	U	V	W	X
7	3	0.0073	1.9419	3.077	5528.6	18.36	0.3162E-01	1393.3	5472.4	-18.5	1000.0	1255.0
7	4	0.0071	1.4952	3.084	5534.7	18.13	0.3129E-01	1393.3	5472.4	-18.5	1000.0	1255.0
7	5	0.0060	1.0167	3.086	5546.1	17.71	0.3069E-01	1393.3	5472.4	-18.5	1000.0	1255.0
7	6	0.0063	0.5149	3.086	5556.8	17.32	0.3012E-01	1393.3	5472.4	-18.5	1000.0	1255.0
7	7	0.0070	-0.0000	3.112	5560.3	17.19	0.2994E-01	1393.3	5472.4	-18.5	1000.0	1255.0
8	1	-0.3445	2.7339	3.084	5534.3	18.14	0.3131E-01	1392.8	5471.1	-134.8	951.2	1255.0
8	2	-0.3601	2.7416	3.079	5528.7	18.32	0.3150E-01	1392.8	5471.1	-134.8	951.2	1255.0
8	3	-0.3712	1.9056	3.078	5529.6	18.32	0.3150E-01	1392.8	5471.1	-134.8	951.2	1255.0
8	4	-0.3825	1.4748	3.086	5536.5	18.06	0.3120E-01	1393.3	5471.1	-134.8	951.2	1255.0
8	5	-0.3825	0.9401	3.084	5548.7	17.62	0.3059E-01	1393.3	5471.1	-134.8	951.2	1255.0
8	6	-0.3576	0.3641	3.111	5559.7	17.21	0.2997E-01	1393.3	5471.1	-134.8	951.2	1255.0
8	7	-0.5085	0.0000	3.113	5560.8	17.17	0.2991E-01	1393.3	5471.1	-134.8	951.2	1255.0
9	1	-0.6988	2.6655	3.084	5534.7	18.13	0.3129E-01	1392.8	5471.1	-134.8	951.2	1255.0
9	2	-0.7229	2.2562	3.074	5530.2	17.46	0.3033E-01	1392.8	5471.1	-134.8	951.2	1255.0
9	3	-0.7355	1.7911	3.074	5530.6	18.29	0.3152E-01	1392.8	5471.1	-134.8	951.2	1255.0
9	4	-0.7419	1.2910	3.087	5531.8	18.01	0.3113E-01	1392.8	5471.1	-134.8	951.2	1255.0
9	5	-0.7139	0.7200	3.101	5550.7	17.54	0.3044E-01	1392.8	5471.1	-134.8	951.2	1255.0
9	6	-0.9356	0.3894	3.103	5552.3	17.48	0.3036E-01	1392.8	5471.1	-134.8	951.2	1255.0
9	7	-1.0132	-0.0000	3.104	5552.7	17.46	0.3033E-01	1392.8	5471.1	-134.8	951.2	1255.0
10	1	-1.0419	2.5510	3.084	5534.9	18.2	0.3129E-01	1390.3	5471.1	-134.8	951.2	1255.0
10	2	-1.0667	2.1155	3.078	5530.3	18.29	0.3152E-01	1390.3	5471.1	-134.8	951.2	1255.0
10	3	-1.0730	1.5191	3.078	5530.8	18.28	0.3150E-01	1392.5	5471.1	-134.8	951.2	1255.0
10	4	-1.0534	0.9204	3.089	5539.0	17.97	0.3108E-01	1392.5	5471.1	-134.8	951.2	1255.0
10	5	-1.2728	0.7509	3.090	5540.3	17.92	0.3109E-01	1392.5	5471.1	-134.8	951.2	1255.0
10	6	-1.4430	0.3892	3.091	5541.2	17.89	0.3095E-01	1392.5	5471.1	-134.8	951.2	1255.0
10	7	-1.4944	-0.0001	3.091	5541.4	17.88	0.3094E-01	1392.5	5471.1	-134.8	951.2	1255.0
11	1	-1.3671	2.3925	3.084	5534.8	18.12	0.3129E-01	1390.4	5471.1	-134.8	951.2	1255.0
11	2	-1.3850	1.9723	3.079	5530.2	18.50	0.3155E-01	1390.4	5471.1	-134.8	951.2	1255.0
11	3	-1.3695	1.3779	3.080	5531.3	18.26	0.3143E-01	1392.0	5471.1	-134.8	951.2	1255.0
11	4	-1.6138	1.0833	3.081	5532.1	18.23	0.3143E-01	1391.2	5471.1	-134.8	951.2	1255.0
11	5	-1.7949	0.7458	3.082	5533.1	18.19	0.3138E-01	1391.0	5471.1	-134.8	951.2	1255.0
11	6	-1.9062	0.3804	3.083	5533.5	18.17	0.3135E-01	1390.9	5471.1	-134.8	951.2	1255.0
11	7	-1.9437	-0.0001	3.083	5533.6	18.17	0.3135E-01	1390.9	5471.1	-134.8	951.2	1255.0
12	1	-1.6886	2.1929	3.084	5534.6	18.13	0.3130E-01	1392.4	5471.1	-134.8	951.2	1255.0
12	2	-1.6885	1.5815	3.079	5530.4	18.29	0.3153E-01	1392.5	5471.1	-134.8	951.2	1255.0
12	3	-1.9119	1.3996	3.080	5530.8	18.23	0.3140E-01	1392.3	5471.1	-134.8	951.2	1255.0
12	4	-2.1091	1.0814	3.081	5531.6	18.22	0.3140E-01	1391.9	5471.1	-134.8	951.2	1255.0
12	5	-2.2521	0.7366	3.081	5532.2	18.22	0.3142E-01	1391.6	5471.1	-134.8	951.2	1255.0
12	6	-2.3602	0.3727	3.082	5532.5	18.21	0.3142E-01	1391.5	5471.1	-134.8	951.2	1255.0
12	7	-2.3696	-0.0001	3.082	5532.5	18.21	0.3142E-01	1391.5	5471.1	-134.8	951.2	1255.0
13	1	-1.9405	1.9564	3.084	5534.7	18.13	0.3129E-01	1392.4	5471.1	-134.8	951.2	1255.0
13	2	-2.1797	1.5865	3.084	5535.0	18.12	0.3128E-01	1392.3	5471.1	-134.8	951.2	1255.0
13	3	-2.3812	1.3667	3.085	5535.6	18.10	0.3128E-01	1392.0	5471.1	-134.8	951.2	1255.0
13	4	-2.5426	1.0621	3.086	5536.2	18.07	0.3128E-01	1391.7	5471.1	-134.8	951.2	1255.0
13	5	-2.6603	0.7183	3.086	5536.6	18.06	0.3119E-01	1391.5	5471.1	-134.8	951.2	1255.0
13	6	-2.7317	0.3619	3.086	5536.7	18.06	0.3119E-01	1391.5	5471.1	-134.8	951.2	1255.0
13	7	-2.7556	-0.0000	3.086	5536.7	18.05	0.3118E-01	1391.4	5471.1	-134.8	951.2	1255.0

XSTEP REGULAT JR PARAMETERS

LIMITING POINT I = 1 AND J = 1 VY FACTOR = 1.05988 DELTA X = 1.0350

EXECUTION TIME 872.8 SECS

Figure 18. (Continued)

SECTION VI  
PROGRAM LISTING

This Section contains the complete listing of the IBM 7094 version of the computer program. The CDC 6500 version is identical except for the necessary changes to the overlay structure and the format of multiple entry points to subroutines.

```

$IBFTC MAIN
C
C
C *****
C
C PROGRAM TITLE--THREE-DIMENSIONAL ANALYSIS OF SUPERSONIC NOZZLE FLOW
C
C *****
C THIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERSITY JET PROPULSION
C CENTER AS A PART OF THE REQUIREMENTS OF AF CONTRACT NUMBER F33615-
C 67-C-1068. THE CONTRACT WAS SPONSORED BY THE AERO PROPULSION
C LABORATORY WRIGHT PATTERSON AFB, OHIO. THE PROGRAM WAS WRITTEN BY
C V.H. RANSOM AND PRINCIPAL INVESTIGATORS FOR PURDUE UNIVERSITY WERE
C PROFESSORS H. DOYLE THOMPSON AND JOE D. HOFFMAN.
C *****
C
C OVERLAY STRUCTURE FOR IBM 7094
C
C MAIN
C BLOCK DATA
C THRUST
C ERRORS
C AROSUB
C WALSUB
C DETERM
C ITER
C NSOLV
C REFLCT
C REFKY
C
C A
C
C SPLINE
C MACHP
C SOURCE
C INVALS
C IVSUB
C
C B B B B C C C
C READIN WALSB2 IVSURF PRNIVS BOUNDR INTER PRNCUT
C TESS INTXRG BPTSUB IPTSUB
C C/PO LADAL BCO, PT COMPAT
C CPMATE
C CROUT
C ARDSB2
C *****
C
C COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,JJ,L,LL,
INSTART,DELX,ODELX,KK,X(2),XMAX,NO
COMMON /CCNST/ PI,DRAD,BYU,G,BYUDG
10 L=1

```

```

MAI 10
MAI 20
MAI 30
MAI 40
MAI 50
MAI 60
MAI 70
MAI 80
MAI 90
MAI 100
MAI 110
MAI 120
MAI 130
MAI 140
MAI 150
MAI 160
MAI 170
MAI 180
MAI 190
MAI 200
MAI 210
MAI 220
MAI 230
MAI 240
MAI 250
MAI 260
MAI 270
MAI 280
MAI 290
MAI 300
MAI 310
MAI 320
MAI 330
MAI 340
MAI 350
MAI 360
MAI 370
MAI 380
MAI 390
MAI 400
MAI 410
MAI 420
MAI 430
MAI 440
MAI 450
MAI 460
MAI 470
MAI 480
MAI 490
MAI 500
MAI 510
MAI 520
MAI 530
MAI 540

```

LL=2  
CALL READIN  
CALL WALS82  
CALL AROS82  
CALL INVAL2  
CALL IVSURF  
I=2  
LL=1  
CALL THRUST  
L=1  
LL=2  
CALL LABAL  
CALL INTXRG  
CALL PRNIVS  
CALL BRAIN  
STOP  
END

MAI 550  
MAI 560  
MAI 570  
MAI 580  
MAI 590  
MAI 600  
MAI 610  
MAI 620  
MAI 630  
MAI 640  
MAI 650  
MAI 660  
MAI 670  
MAI 680  
MAI 690  
MAI 700  
MAI 710-

```
$IBMAP UNIT  
ENTRY .UN07.  
.UN07. PZE UNIT07  
UNIT07 FILE ,UT1,MOUNT,INPUT,BLK=256,PIN  
END
```

```

$IBFTC CNSTNT
BLOCK DATA
COMMON /XRGLT/ RM(2,19,19),DXDL(2,19,19),EXCNTR,DELMN,PPM,hhh,SAFBKD 10
ITY
COMMON /CCNST/ PI,DRAD,BTU,G,BTUOG
COMMON /AR01/ GAMMA,RGAS,GAM1,GAM2,GAM3,GAM4,GAM5,PTAB(30),ACO(4,38KD 40
10),ROCO(4,30),TCO(4,30),QSCO(4,30),NFDE,NTHERM,IIII,PSOURC
COMMON /AR02/ ATAB(30,2),ROTAB(30,2),TIAB(30,2),QSTAB(30,2),PTAB(38KD 70
10)
COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,JJ,L,LL,BKD 80
INSTART,DELX,ODELX,KK,X(2),XMAX,NO
COMMON /IVS/ XSORC,YSORC,ZSORC,XIVS,YCIVS,ZCIVS,MCIVS,PHICIV,THECIBKD 110
IV,PTCIVS,HCIVS,RIVS,MIVS,THETIV,PSIIV,PTIVS,HIVS,XPSORC,YPSORC,ZPSBK
2ORC,ALPSRC,BETSRC
COMMON /PLANES/ NPOS,NX1,NY1,NZ1,NX2,NY2,NZ2
COMMON /WALS8/ YAXIS,ZAXIS,XT(4),RT(4),RC(4),THETAT(4),XE(4),RE(4)BKD 150
1,THETA(4),NSYMMY,XY1(4),EXPY1(4),X12(4),EXPY2(4),DEDXY2(4),EXPY3(4)BKD 160
24),XZ1(4),EXPZ1(4),XZ2(4),EXPZ2(4),DEDXZ2(4),EXPZ3(4),XY3(4),XZ3(4)BKD 170
3)
COMMON /COEF1/ XX(4),RR(4),AK(4),XXT(4),YT(4),AN(4),BN(4),CN(4),DNBKD 180
1(4),EN(4),AAY(4),BAY(4),CAY(4),ABY(4),BBY(4),CXY(4),AAZ(4),BAZ(4),BKD 200
2CAZ(4),ABZ(4),BBZ(4),CBZ(4),AYTEST(4),AZTEST(4),BYTEST(4),BZTEST(4)BKD 210
3),SYMMY(4)
COMMON /THRU1/ AREA,AREAT,FMASS,XTMRI,YTHRI,ZTHRI,XTHR,YTHR,ZTHR,XBKD 230
1MCMT,YMOMT,ZMOMT,PAMB,FMASS1,RMASS
DIMENSION RIVS(30), MIVS(30), THETIV(30), PTIVS(30,2), HIVS(30,2),BKD 250
1 PSIIV(30)
REAL MCIVS,NX1,NY1,NZ1,NX2,NY2,NZ2,MTAB
INTEGER PRINT1,PRINT2
C
C LOAD DEFAULT VALUES FOR INPUT PARAMETERS AND PROGRAM CONSTANTS
C
DATA PI,DRAD,BTUOG,G/3.1415926,0.017453292,25036.639,32.1739/
DATA PRINT1,PRINT2,ERROR,IVSTYP,NPOS/0,1,0.0C01,0.0/,GAMMA,RGAS/0.8KD 330
10,1.0/,XSORC,YSORC,ZSORC,XIVS,YCIVS,ZCIVS,MCIVS,PHICIV,THECIV,PTCIBKD 340
2VS,HCIVS/0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0/
30.0,0.0,-1.0/,XMAX/0.0/
DATA YAXIS,ZAXIS/0.0,0.0/
DATA (XT(I),I=1,4)/4*0.0/
DATA (RT(I),I=1,4)/4*1.0/
DATA (RC(I),I=1,4)/4*1.0/
DATA (THETAT(I),I=1,4)/4*0.0/
DATA (XE(I),I=1,4)/4*0.0/
DATA (RE(I),I=1,4)/4*0.0/
DATA (THETA(1),I=1,4)/4*0.0/
DATA (SYMMY(1),I=1,4),NSYMMY/4*2.,1/
DATA (XY1(I),I=1,4)/4*0.0/
DATA (X12(I),I=1,4)/4*1.0/
DATA (XY3(I),I=1,4)/4*10.0/
DATA (XZ1(I),I=1,4)/4*0.0/
DATA (XZ2(I),I=1,4)/4*1.0/
DATA (XZ3(I),I=1,4)/4*10.0/
DATA (DEDXY2(1),I=1,4)/4*0.0/
DATA (DEDXZ2(1),I=1,4)/4*0.0/
DATA (EXPY1(1),I=1,4)/4*2.0/

```

DATA (EXPY2(I),I=1,4)/4\*2.0/  
 DATA (EXPY3(I),I=1,4)/4\*2.0/  
 DATA (EXP21(I),I=1,4)/4\*2.0/  
 DATA (EXP22(I),I=1,4)/4\*2.0/  
 DATA (EXP23(I),I=1,4)/4\*2.0/  
 DATA (MTAB(I),I=1,30)/30\*0.0/  
 DATA SAFETY/0.64/  
 DATA PAMB/0.0/  
 DATA NTHERM/0/  
 DATA NSTART/-1/  
 END

BKD 550  
 BKD 560  
 BKD 570  
 BKD 580  
 BKD 590  
 BKD 600  
 BKD 610  
 BKD 620  
 BKD 630  
 BKD 640  
 BKD 650-

```

$IBFTC THRUST
SUBROUTINE THRUST
C
C *****
C
C CALCULATE CROSS SECTIONAL AREA, WEIGHT FLOW, THRUST COMPONENTS,
C AND MOMENTS. THE DEPENDENT VARIABLES ARE CONVERTED TO ENGINEERING
C UNITS FOR PRINTING.
C
C *****
C
COMMON /SOLUTN/ Y(2,19,19),Z(2,19,19),U(2,19,19),V(2,19,19),W(2,19,19),P(2,19,19),PT(19,19),H(19,19),KLASS(19,19)
COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IYSTYP,ICLASS,NP,NT,II,JJ,L,LL,INSTA,I,DELX,ODELX,KK,X(2),XMAX,NO
COMMON /THRUT/ AREA,AREAT,FMASS,XTHR1,YTHR1,ZTHR1,XTHR,YTHR,ZTHR,XTHR
COMMON /CCNST/ PI,DRAD,BTU,G,BTUGG
DATA NSKIP/1/
C
C SET INITIAL VALUES TO ZERO
C
AREAT=0.0
XTHR=0.0
YTHR=0.0
ZTHR=0.0
FMASS=0.0
XMCMT=0.0
YMCMT=0.0
ZMCMT=0.0
NJ=1
C
C ESTABLISH RANGES FOR INTERGRATION DO LOOPS
C
GO TO (10,10,20,30), ICLASS
10 NJ=NP
NI=NP
GO TO 40
C
20 NI=NT
NJ=NP
GO TO 40
C
30 NI=NT
NJ=NT
40 DO 50 I=1,NI
IF (ICLASS.EQ.1) NJ=1
DO 50 J=NJ1,NJ
C
C CALCULATE A, RQ, QS, AND T AT EACH POINT
C
CALL ARQS3 (PILL,I,J),PT(I,J),H(I,J),A,RC,QS,T)
U(I,I,J)=RQ
C
C CONVERT UNITS AND STORE IN UNUSED SIDE OF ARRAYS

```

```

C      Y(L,I,J)=P(LL,I,J)/144.0
C      V(L,I,J)=RO*G
C      Z(L,I,J)=SQRT(QS)
C      W(L,I,J)=Z/L,I,J)/A
50    P(L,I,J)=T
C
C      CALCULATE NUMBER OF ONE-EIGHTH SECTORS OF SOLUTION SURFACE
C      NSECT=2**((ICLASS-1)
C      NP1=NP-1
C
C      INTEGRATION LOOPS
C      TOTAL SECTORS
C      DO 230 K=1,NSECT
C      EACH SECTOR IS INTEGRATED BY SUMMING TRIANGULAR REGIONS
C      DO 230 I11=1,NP1
C      NSW=2
C      DO 230 JJ1=I11,NP
C      IF (JJ1.EQ.NP1) NSW=1
C      DO 230 NTR=1,NSW
C      GENERATE INDICES OF EACH TRIANGULAR ELEMENT OF INTEGRAL
C      DO 220 KK1=1,3
C      GO TO (60,70,80), KK1
60    I=I11
C      J=JJ1+NTR-1
C      GO TO 90
C
70    I=I11+NTR-1
C      J=JJ1+1
C      GO TO 90
C
C      I=I11+1
C      J=JJ1+NTR
90    GO TO (100,110,120,130,140,150,160,170), K
100   I1=I
C      J1=J
C      GO TO 180
C
110   I1=J
C      J1=I
C      GO TO 180
C
120   I1=NT+1-J
C      J1=J
C      GO TO 180
C
130   I1=NT+1-I
C      J1=J
C      GO TO 180
C

```

```

THR 55
THR 56
THR 57
THR 58
THR 59
THR 60
THR 61
THR 62
THR 63
THR 64
THR 65
THR 66
THR 67
THR 68
THR 69
THR 70
THR 71
THR 72
THR 73
THR 74
THR 75
THR 76
THR 77
THR 78
THR 79
THR 80
THR 81
THR 82
THR 83
THR 84
THR 85
THR 86
THR 87
THR 88
THR 89
THR 90
THR 91
THR 92
THR 93
THR 94
THR 95
THR 96
THR 97
THR 98
THR 99
THR100
THR101
THR102
THR103
THR104
THR105
THR106
THR107
THR108
THR109
THR110

```

140	I1=NT+1-I	THR1110
	J1=NT+1-J	THR1120
	GO TO 180	THR1130
C		THR1140
150	I1=NT+1-J	THR1150
	J1=NT+1-I	THR1160
	GO TO 180	THR1170
C		THR1180
160	I1=J	THR1190
	J1=NT+1-I	THR1200
	GO TO 180	THR1210
C		THR1220
170	I1=I	THR1230
	J1=NT+1-J	THR1240
180	GO TO (190,200,210), KX1	THR1250
190	M1=I1	THR1260
	N1=J1	THR1270
	GO TO 220	THR1280
C		THR1290
200	M2=I1	THR1300
	N2=J1	THR1310
	GO TO 220	THR1320
C		THR1330
210	M3=I1	THR1340
	N3=J1	THR1350
220	CONTINUE	THR1360
C		THR1370
C	CALCULATE AREA OF TRIANGULAR ELEMENT	THR1380
C		THR1390
	AREA=0.5*ABS(Y(LL,M1,N1)*(Z(LL,M2,N2)-Z(LL,M3,N3))+Y(LL,M2,N2)*(Z(LL,M3,N3)-Z(LL,M1,N1))+Y(LL,M3,N3)*(Z(LL,M1,N1)-Z(LL,M2,N2)))	THR1400
1		THR1410
2		THR1420
	AREA3=AREA/3.0/144.0	THR1430
C		THR1440
C	CALCULATE CENTROID	THR1450
C		THR1460
	YBAR=(Y(LL,M1,N1)+Y(LL,M2,N2)+Y(LL,M3,N3))/3.0	THR1470
	ZBAR=(Z(LL,M1,N1)+Z(LL,M2,N2)+Z(LL,M3,N3))/3.0	THR1480
C		THR1490
C	CALCULATE MASS FLUXES	THR1500
C		THR1510
	ROU1=U(L,M1,N1)*U(LL,M1,N1)	THR1520
	ROU2=U(L,M2,N2)*U(LL,M2,N2)	THR1530
	ROU3=U(L,M3,N3)*U(LL,M3,N3)	THR1540
C		THR1550
C	SUM MASS FLOW AND AREA	THR1560
C		THR1570
	FMASS=FMASS+(ROU1+ROU2+ROU3)*AREA3	THR1580
	AREAT=AREAT+AREA	THR1590
C		THR1600
C	CALCULATE THRUST COMPONENTS	THR1610
C		THR1620
	XTHR1=-AREA3*(ROU1*U(LL,M1,N1)+ROU2*U(LL,M2,N2)+ROU3*U(LL,M3,N3)-P(LL,M1,N1)+P(LL,M2,N2)+P(LL,M3,N3))*AREA3+AREA*PAMB	THR1630
1		THR1640
	YTHR1=-AREA3*(ROU1*V(L,M1,N1)+ROU2*V(LL,M2,N2)+ROU3*V(LL,M3,N3)-P(LL,M1,N1)+P(LL,M2,N2)+P(LL,M3,N3))*AREA3+AREA*PAMB	THR1650
1		THR1660

	ZTHR1=-AREA3*(ROU1*W(11,1)+ROU2*W(11,2)+ROU3*W(11,3),N3THR1670	
1	11	
C		THR1680
C	SUM MOMENTS	THR1690
C		THR1700
	XMONT=XMONT+ZTHR1*YBAR-YTHR1*ZBAR	THR1710
	YMONT=YMONT+XTHR1*ZBAR-ZTHR1*X(11)	THR1720
	ZMONT=ZMONT+YTHR1*X(11)-XTHR1*YBAR	THR1730
C		THR1740
C	SUM THRUSTS	THR1750
C		THR1760
	XTHR=XTHR+XTHR1	THR1770
	YTHR=YTHR+YTHR1	THR1780
230	ZTHR=ZTHR+ZTHR1	THR1790
C		THR1800
C	CONVERT MASS FLOW TO WEIGHT FLOW	THR1810
C		THR1820
	FMASS=FMASS*G	THR1830
	GO TO (240,250). NSKIP	THR1840
240	FMASS1=FMASS	THR1850
	NSKIP=2	THR1860
	GO TO 260	THR1870
C		THR1880
C	NORMALIZE THE THRUST COMPONENTS BY THE MASS FLOW RATE RATIO	THR1890
C		THR1900
250	RMASS=FMASS1/FMASS	THR1910
	XTHR=XTHR/RMASS	THR1920
	YTHR=YTHR/RMASS	THR1930
	ZTHR=ZTHR/RMASS	THR1940
260	RETURN	THR1950
	END	THR1960
		THR1970-

SIBFIC ERRORS		
	SUBROUTINE ERRORS (MISTAK)	ERR 10
C		ERR 20
C	*****	ERR 30
C		ERR 40
C	DIAGNOSTIC ERROR MESSAGES FOR SOME OF THE ANTICIPATED MODES OF	ERR 50
C	FAILURE OF THE PROGRAM	ERR 60
C		ERR 70
C	*****	ERR 80
C		ERR 90
	GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160), MISTAK	ERR 100
C		ERR 110
10	WRITE (6,170)	ERR 120
	STOP	ERR 130
C		ERR 140
20	WRITE (6,180)	ERR 150
	STOP	ERR 160
C		ERR 170
30	WRITE (6,190)	ERR 180
	STOP	ERR 190
C		ERR 200
40	WRITE (6,200)	ERR 210
	STOP	ERR 220
C		ERR 230
50	WRITE (6,210)	ERR 240
	STOP	ERR 250
C		ERR 260
60	WRITE (6,220)	ERR 270
	RETURN	ERR 280
C		ERR 290
70	WRITE (6,230)	ERR 300
	RETURN	ERR 310
C		ERR 320
80	WRITE (6,240)	ERR 330
	STOP	ERR 340
C		ERR 350
90	WRITE (6,250)	ERR 360
	STOP	ERR 370
C		ERR 380
100	WRITE (6,260)	ERR 390
	STOP	ERR 400
C		ERR 410
110	WRITE (6,270)	ERR 420
	STOP	ERR 430
C		ERR 440
120	WRITE (6,280)	ERR 450
	STOP	ERR 460
C		ERR 470
130	WRITE (6,290)	ERR 480
	STOP	ERR 490
C		ERR 500
140	WRITE (6,300)	ERR 510
	STOP	ERR 520
C		ERR 530
		ERR 540

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150  WRITE (6,310)                                ERR 550
      STOP                                          ERR 560
C                                           ERR 570
160  WRITE (6,320)                                ERR 580
      STOP                                          ERR 590
C                                           ERR 600
C                                           ERR 610
170  FORMAT (1H0,10X,110H****ERROR STOP 1 - CALLED FROM SUBROUTINE REAERR 620
      1DIN. INCORRECT SPECIFICATION OF INITIAL VALUE SURFACE TYPE, THE/1ERR 630
      2H0,10X,54HPARAMETER IVSTYP CAN ONLY HAVE VALUES 1,2,3 OR 4.****) ERR 640
180  FORMAT (1H0,10X,114H****ERROR STOP 2 - CALLED FROM SUBROUTINE REAERR 650
      1DIN. INCORRECT SPECIFICATION OF BOUNDARY TYPE, THE PARAMETER NSYPERR 660
      2HY/1H0,10X,35HCAN ONLY HAVE VALUES 1,2 OR 3.****) ERR 670
190  FORMAT (1H0,10X,112H****ERRGR STOP 3 - CALLED FROM SUBROUTINE PMAERR 680
      1CH. CONVERGENCE FAILURE IN ATTEMPTING TO SOLVE FOR PRESSURE.****ERR 690
      2) ERR 700
200  FORMAT (1H0,10X,73H****ERROR STOP 4 - CALLED FROM BRAIN. NC STARERR 710
      1T POINT FOUND ON TAPE****) ERR 720
210  FORMAT (1H0,10X,112H****ERROR STOP 5 - CALLED FROM SUBROUTINE SOUERR 730
      1RCE. FAILED TO CONVERGE IN 50 ITERATIONS, USUAL TROUBLE IS THAT AERR 740
      2/1H0,10X,55HSOLUTION FOR A SUBSONIC MACH NUMBER IS ATTEMPTED.****ERR 750
      3*) ERR 760
220  FORMAT (1H0,10X,113H****ERROR WARNING 6 - CALLED FROM SUBROUTINE ERR 770
      1INVALS. INITIAL DATA IS EXTRAPOLATED USING LAST SPLINE, ERRORS MAERR 780
      2Y/1H0,10X,12HRESULT.****) ERR 790
230  FORMAT (1H0,10X,111H****ERROR WARNING 7 - CALLED FROM SUBROUTINE ERR 800
      1INVALS. LAST POINT OF TABULAR AXISYMMETRIC INITIAL DATA DOES NOT/ERR 810
      21H0,10X,57HOCORRESPOND TO THE NOZZLE BOUNDARY, ERRORS MAY OCCUR.****ERR 820
      3*) ERR 830
240  FORMAT (1H0,10X,114H****ERROR STOP 8 - CALLED FROM SUBROUTINE INVERR 840
      1ALS OR IVSUB. A MACH NUMBER LESS THAN OR EQUAL TO 1.0 WAS SPECIFIERR 850
      2ED/1H0,10X,48HOR CALCULATED ON THE INITIAL VALUE SURFACE.****) ERR 860
250  FORMAT (1H0,10X,112H****ERROR STOP 9 - CALLED FROM SUBROUTINE INVERR 870
      1ALS. A TABULAR INPUT INITIAL VALUE SURFACE HAVING NON ZERO VALUESERR 880
      2/1H0,10X,68HOF PSI WAS SPECIFIED WITH A GEOMETRY HAVING PLANES OF ERR 890
      3SYMMETRY.****) ERR 900
260  FORMAT (1H0,10X,81H****ERROR STOP 10 - CALLED FROM SUBROUTINE KEAERR 910
      1CIN. XMAX WAS NOT SPECIFIED.****) ERR 920
270  FORMAT (1H0,10X,115H****ERROR STOP 11-CALLED FROM SUBROUTINE IPTSERR 930
      1UB. INTERIOR POINT SOLUTION FAILED TO CONVERGE IN 20 ITERATIONS.***ERR 940
      2****) ERR 950
280  FORMAT (1H0,10X,115H****ERROR STOP 12-CALLED FROM SUBROUTINE BPTSERR 960
      1UB. BOUNDARY POINT SOLUTION FAILED TO CONVERGE IN 20 ITERATIONS.***ERR 970
      2****) ERR 980
290  FORMAT (1H0,10X,102H****ERROR STOP 13 - CALLED FROM AROSUB. ATTEPERR 990
      1PTED TO CALCULATE THERMODYNAMIC DATA AT A PRESSURE OUTSIDE THE/1H0ERR1000
      2,15X,32HLIMITS OF THE TABULAR INPUT DATA) ERR1010
300  FORMAT (1H0,10X,105H****ERROR STOP 14 - CALLED FROM AROSUB. MACHEERR1020
      1NUMBERS OF TABULAR DATA DO NOT MONOTONICALLY INCREASE****) ERR1030
310  FORMAT (1H0,10X,115H****ERRROR STOP 15 - CALLED FROM BRAIN. THE PERR1040
      1PARAMETERS READ FROM TAPE DO NOT AGREE WITH DATA INPUT FROM CARDS**ERR1050
      2****) ERR1060
320  FORMAT (1H0,10X,112H****ERROR STOP 16 - CALLED FROM ITER. ITERATIERR1070
      1VE SOLUTION FOR A POINT ON THE BOUNDARY EXCEEDED 25 ITERATIONS****ERR1080
      2) ERR1090
      END ERR1100-

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$IDFTC ARQSUB
SUBROUTINE ARQSUB (P,PT,H,A,RO,QS,DADP,DADPT,DADH,DRODP,DRODPT,DRODHO 10
10H) ARO 20
C ARO 30
C ***** ARO 40
C ARO 50
C THE PROPERTIES A, RO AND Q ARE CALCULATED AS A FUNCTION OF P, PT AND ARO 60
C EITHER A NONHENTROPIC FLOW OF A CALORICALLY AND THERMALLY PERFECT ARO 70
C GAS OR A HENTROPIC FLOW OF A GAS IN CHEMICAL EQUILIBRIUM IS ARO 80
C ASSURED. IF GAMMA IS SPECIFIED THEN THE FORMER, IF NOT THEN THE ARO 90
C LATTER IF A TABLE OF P, RO, AND A VERSUS MACH NO- IS PROVIDED. ARO 100
C ARO 110
C UNITS OF P AND PT ARE LB/FT**2 ARO 120
C UNITS OF H ARE FT-LB/SLUG ARO 130
C UNITS OF A ARE FT/SEC ARO 140
C UNITS OF RO ARE SLUGS/FT**3 ARO 150
C ***** ARO 160
C ***** ARO 170
C ARO 180
C REAL MTAB ARO 190
COMMON /AR01/ GAMMA, RGAS, GAM1, GAM2, GAM3, GAM4, GAM5, PTAB(30), ACQ(4,3) ARO 200
10), ROQ(4,30), TCO(4,30), QSC(4,30), NFOE, NTHETA, I, PSOURC ARO 210
COMMON /CCNST/ P1, DRAD, BTU, C, BTUDG ARO 220
NENT=1 ARO 230
GO TO 10 ARO 240
C ARO 250
C CALCULATE A, RO AND QS ONLY ARO 260
C ARO 270
C ENTRY ARQSB1(P,PT,H,A,RO,QS) ARO 280
C ARO 290
C NENT=2 ARO 300
GO TO 10 ARO 310
C ARO 320
C CALCULATE A, RO, QS AND T (DADP) ONLY ARO 330
C ARO 340
C ENTRY ARQSB3(P,PT,H,A,RO,QS,DADP) ARO 350
C ARO 360
C NENT=3 ARO 370
GO TO 10 ARO 380
C ARO 390
C CONSTANT GAMMA, NFOE = 1, OR EQUILIBRIUM, NFOE = 2 ARO 400
C ARO 410
10 GO TO (20,60), NFOE ARO 420
20 GS=2.0*H*(1.0-(P/PT)**GAM1) ARO 430
ASQ=GAM3*H*(P/PT)**GAM1 ARO 440
RO=GAMMA*P/ASQ ARO 450
A=SQRT(ASQ) ARO 460
GO TO (30,40,50), NENT ARO 470
30 CADP=GAM1*A/(2.0*P) ARO 480
DADPT=-DADP*P/PT ARO 490
DADH=A/(2.0*H) ARO 500
DRODP=1.0/ASQ ARO 510
CRODPT=GAM1*RO/PT ARO 520
DRODH=-RO/H ARO 530
40 RETURN ARO 540

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50	DADP=P/(RO*G*RGAS)	ARO 550
	RETURN	ARO 560
C		ARO 570
C	TABLE SEARCH	ARO 580
C		ARO 590
60	IF (P.GE.PTAB(I)) GO TO 70	ARO 600
	I=I+1	ARO 610
C		ARO 620
C	RAN OFF TABLE AT LOW P END	ARO 630
C		ARO 640
	IF (I.GT.NTHERM) CALL ERRORS (13)	ARO 650
	GO TO 60	ARO 660
C		ARO 670
70	IF (P.LE.PTAB(I-1)) GO TO 80	ARO 680
	I=I-1	ARO 690
C		ARO 700
C	RAN OF TABLE AT HIGH P END	ARO 710
C		ARO 720
	IF (I.EQ.1) CALL ERRORS (13)	ARO 730
	GO TO 70	ARO 740
C		ARO 750
80	DELP=P-PTAB(I-1)	ARO 760
C		ARO 770
C	MULTIPLE ENTRY OPTIONS - EVALUATE DATA FROM CUBIC SPLINE	ARO 780
C		ARO 790
	GO TO (90,100,110), NEXT	ARO 800
90	A=ACO(1,I)+ACO(2,I)*DELP+ACO(3,I)*DELP**2+ACO(4,I)*DELP**3	ARO 810
	RO=ROCO(1,I)+ROCO(2,I)*DELP+ROCO(3,I)*DELP**2+ROCO(4,I)*DELP**3	ARO 820
	CS=QSCO(1,I)+QSCO(2,I)*DELP+QSCO(3,I)*DELP**2+QSCO(4,I)*DELP**3	ARO 830
	DADP=ACO(2,I)+2.0*ACO(3,I)*DELP+3.0*ACO(4,I)*DELP**2	ARO 840
	CRODP=ROCO(2,I)+2.0*ROCO(3,I)*DELP+3.0*ROCO(4,I)*DELP**2	ARO 850
	DADPT=0.0	ARO 860
	CADH=0.0	ARO 870
	CHODPT=0.0	ARO 880
	CRODH=0.0	ARO 890
	RETURN	ARO 900
100	A=ACO(1,I)+ACO(2,I)*DELP+ACO(3,I)*DELP**2+ACO(4,I)*DELP**3	ARO 910
	RO=ROCO(1,I)+ROCO(2,I)*DELP+ROCO(3,I)*DELP**2+ROCO(4,I)*DELP**3	ARO 920
	QS=QSCO(1,I)+QSCO(2,I)*DELP+QSCO(3,I)*DELP**2+QSCO(4,I)*DELP**3	ARO 930
	RETURN	ARO 940
110	A=ACO(1,I)+ACO(2,I)*DELP+ACO(3,I)*DELP**2+ACO(4,I)*DELP**3	ARO 950
	RO=ROCO(1,I)+ROCO(2,I)*DELP+ROCO(3,I)*DELP**2+ROCO(4,I)*DELP**3	ARO 960
	CS=QSCO(1,I)+QSCO(2,I)*DELP+QSCO(3,I)*DELP**2+QSCO(4,I)*DELP**3	ARO 970
	DADP=TCO(1,I)+TCO(2,I)*DELP+TCO(3,I)*DELP**2+TCO(4,I)*DELP**3	ARO 980
	RETURN	ARO 990
	END	ARO 1000-

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SIBFTC WALSUB
SUBROUTINE WALSUB (X,Y,Z,XDN,YDN,ZDN)
C
C *****
C
C WALSUB AND ITS ASSOCIATED SUBROUTINES ARE USED TO DEFINE THE
C PHYSICAL BOUNDARY OF THE FLOW. OPTIONS INCLUDE AN AXISYMMETRIC
C BOUNDARY FORMED BY A CIRCULAR ARC IN THE THROAT REGION JOINED TANG-
C ENTIALY TO A GENERAL PARABOLA FOR THE EXPANSION SECTION, SUPER-
C ELLIPTICAL CONTOURS HAVING TWO PLANES OF SYMMETRY AND SUPER-ELLIP-
C TICAL CONTOURS HAVING NO PLANES OF SYMMETRY. THE SUBPROGRAM WALSB2
C MUST BE CALLED FIRST IN ORDER TO INITIALIZE THE SUBROUTINES.
C THE ARGUMENTS PASSED INTO THE SUBROUTINE ARE THE COORDINATES OF A
C POINT AND THE DIRECTION COSINES OF A LINE THROUGH THE POINT. THE
C SUBROUTINE THEN LOCATES THE NEAREST INTERSECTION OF THE LINE WITH
C THE WALL. THE SUBPROGRAMS USED BY WALSUB ARE DETERM, ITER AND NSOLV
C
C WRITTEN BY S. KISSICK JUNE 1969
C
C *****
C
C PASS PARAMETERS TO ITER
C
C COMMON /FUNX/ P1,P2,P3,P4,C2,C3,C4,C5,CC
C
C PARAMETERS FROM WALSB2
C
C COMMON /TRANS/ Y0,Z0,NSYMMY
C
C PARAMETERS FROM NSOLV
C
C COMMON /NSLV/ XNORM,YNORM,ZNORM
C
C THE PARAMETER X1 IS NOT P1
C
C DATA NQ1,X1,KCT/0.3,14159991,1/
C GO TO 10
C
C ENTRY POINT WALSB1 IS CALLED WHEN THE ARGUMENTS X,Y, AND Z ARE
C KNOWN TO BE A SOLUTION AND COMPONENTS OF THE NORMAL ARE DESIRED.
C THIS PROGRAM DOES NOT TAKE ADVANTAGE OF THIS FEATURE
C
C ENTRY WALSB1(X,Y,Z,XDN,YDN,ZDN)
C
C XDN=0.0
C Y0=Y-Y0
C Z0=Z-Z0
C D=SQRT(Y0**2+Z0**2)
C YDN=Y0/D
C ZDN=Z0/D
C YCOS=YDN
C ZCOS=ZDN
C GO TO 20
C
C 10 CONTINUE
C
C NORMALIZE THE DIRECTION RATIOS

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```

WAL 10
WAL 20
WAL 30
WAL 40
WAL 50
WAL 60
WAL 70
WAL 80
WAL 90
WAL 100
WAL 110
WAL 120
WAL 130
WAL 140
WAL 150
WAL 160
WAL 170
WAL 180
WAL 190
WAL 200
WAL 210
WAL 220
WAL 230
WAL 240
WAL 250
WAL 260
WAL 270
WAL 280
WAL 290
WAL 300
WAL 310
WAL 320
WAL 330
WAL 340
WAL 350
WAL 360
WAL 370
WAL 380
WAL 390
WAL 400
WAL 410
WAL 420
WAL 430
WAL 440
WAL 450
WAL 460
WAL 470
WAL 480
WAL 490
WAL 500
WAL 510
WAL 520
WAL 530
WAL 540

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C	C=SQRT(YDN**2+ZDN**2)	HAL 550
	YCOS=YDN/D	HAL 560
	ZCOS=ZDN/D	HAL 570
	YOP=Y-YO	HAL 580
	ZOP=Z-ZO	HAL 590
C		HAL 600
C	IF KCT = 3 CCNTOUR IS ASYMMETRIC	HAL 610
C		HAL 620
20	GO TO (30,50,190), KCT	HAL 630
30	KCT=2	HAL 640
	GO TO (40,50), NSYMM	HAL 650
C		HAL 660
C	CALLED ONLY ONCE FOR AN AXISYMMETRIC NOZZLE	HAL 670
C		HAL 680
40	CALL DETRM2 (YOP,ZOP,YDN,ZDN,ANY,BNY,CNY,DNY,ENY,ANZ,BNZ,CNZ,DNZ,EWAL	HAL 690
	1NZ,AKY,AKZ,RCY,RCZ,XOY,XOZ,AAV,BAY,CAY,ABY,BBY,CBY,AAZ,BAZ,CAZ,ABZ	HAL 700
	WAL 710	HAL 720
	2,3BZ,CBZ,AYTEST,AZTEST,BYTEST,BZTEST,NSYMQD,XTY,XTZ,NQ,XY2,XZ2)	HAL 730
	NQ=1	HAL 740
	KCT=3	HAL 750
	GO TO 190	HAL 760
C		HAL 770
50	CALL DETERM (YOP,ZOP,YDN,ZDN,ANY,BNY,CNY,DNY,ENY,ANZ,BNZ,CNZ,DNZ,EWAL	HAL 780
	1NZ,AKY,AKZ,RCY,RCZ,XOY,XOZ,AAV,BAY,CAY,ABY,BBY,CBY,AAZ,BAZ,CAZ,ABZ	HAL 790
	WAL 800	HAL 810
C	IF NSYMQD = 1 ALL QUADRANTS OF THE NOZZLE ARE THE SAME, I.E., 2POS	HAL 820
C		HAL 830
	GO TO (60,70), NSYMQD	HAL 840
60	IF (X.EQ.X1.AND.NQ.EQ.NQ1) GO TO 200	HAL 850
	GO TO 80	HAL 860
C		HAL 870
70	IF (X.EQ.X1.AND.NQ.EQ.NQ1) GO TO 180	HAL 880
C		HAL 890
C	TEST X TO SEE IF ON CIRCULAR ARC OR PARABOLIC WALL	HAL 900
C		HAL 910
80	IF (X.LE.XTY) GO TO 90	HAL 920
C		HAL 930
C	COMPUTE SUPER-ELLIPTICAL EXPONENTS	HAL 940
C		HAL 950
	BQ=(X*ANY+CNY)	HAL 960
	CQ=(BNY*X**2+DNY*X+ENY)	HAL 970
	R=-BQ*.5+.5*SQRT(BQ**2-4.*CQ)	HAL 980
	DBDX=-(DNY+2.*BNY*X+ANY*B)/(2.*B+ANY*X+CNY)	HAL 990
	GO TO 100	HAL 1000
C		HAL 1010
90	B=AKY-SQRT(RCY**2-(X-XOY)**2)	HAL 1020
	DBDX=-(X-XOY)/(B-AKY)	HAL 1030
100	GO TO (200,110), NSYMQD	HAL 1040
110	IF (X.LE.XTZ) GO TO 120	HAL 1050
	BQ=(X*ANZ+CNZ)	HAL 1060
	CQ=(BNZ*X**2+DNZ*X+ENZ)	HAL 1070
	A=-BQ*.5+.5*SQRT(BQ**2-4.*CQ)	HAL 1080
	CAOT=-(DNZ+2.*BNZ*X+ANZ*A)/(2.*A+ANZ*X+CNZ)	HAL 1090
	GO TO 130	HAL 1100
C		

120	A=AKZ-SQRT(RCZ**2-(X-XOZ)**2)	WAL1110
	DADX=-(X-XOZ)/(A-AKZ)	WAL1120
130	CONTINUE	WAL1130
	IF (X.GE.XYZ) GO TO 140	WAL1140
	EY=ABY+BBY*X+CBY*X**2	WAL1150
	DEYDX=BBY+2.*CBY*X	WAL1160
	NSOLY=BYTEST	WAL1170
	GO TO 150	WAL1180
C		WAL1190
140	EY=AAZ+BAY*X+CAY*X**2	WAL1200
	DEYDX=BAZ+2.*CAY*X	WAL1210
	NSOLY=AYTEST	WAL1220
150	IF (X.GE.XZZ) GO TO 160	WAL1230
	EZ=ABZ+BBZ*X+CBZ*X**2	WAL1240
	DEZDX=BBZ+2.*CBZ*X	WAL1250
	NSOLZ=BZTEST	WAL1260
	GO TO 170	WAL1270
C		WAL1280
160	EZ=AAZ+BAZ*X+CAZ*X**2	WAL1290
	DEZDX=BAZ+2.*CAZ*X	WAL1300
	NSOLZ=AZTEST	WAL1310
C		WAL1320
C	EVALUATE CONSTANTS USED IN ITER	WAL1330
C		WAL1340
170	P1=EZ-1.	WAL1350
	P2=EY-1.	WAL1360
	P3=EZ-2.	WAL1370
	P4=EY-2.	WAL1380
	C1=B**EY	WAL1390
	C2=A**EZ	WAL1400
	C4=C2*C3	WAL1410
	C5=EZ**1.2	WAL1420
	CC=E**1.3	WAL1430
180	CONTINUE	WAL1440
	CALL OLV (A,B,ZOP,YOP,ZON,YON,EZ,EY,Z1,Y1,NSOLZ,NSOLY,DADX,DBDX,ICEZDX,CCYDX)	WAL1450
	NQ1=NQ	WAL1460
	X1=X	WAL1470
	Y=Y1+Y0	WAL1480
	Z=Z1+Z0	WAL1490
	XDN=XNORM	WAL1500
	YDN=YNORM	WAL1510
	ZDN=ZNORM	WAL1520
	RETURN	WAL1530
C		WAL1540
C	SOLVE DIRECTLY WHEN CONTOUR IS AXISYMMETRIC	WAL1550
C		WAL1560
190	IF (X.NE.X1) GO TO 80	WAL1570
200	ROP=SQRT(YOP**2+ZOP**2)	WAL1580
	Y=Y0+YOP/ROP*B	WAL1590
	Z=Z0+ZOP/ROP*B	WAL1600
	DENOM=SQRT(DBDX**2+1.)	WAL1610
	XDN=-DBDX/DENOM	WAL1620
	YDN=YOP/ROP/DENOM	WAL1630
	ZDN=ZOP/ROP/DENOM	WAL1640
	NQ1=NQ	WAL1650
	X1=X	WAL1660
	RETURN	WAL1670
	END	WAL1680
		WAL1690-

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#IDFIC DETERM
SUBROUTINE DETERM (Y,X,YDN,XDN,ANI,BNI,CNI,DNI,ENI,ANJ,BNJ,CNJ,DNJDET 10
1,ENJ,AKI,AKJ,RCI,RCJ,XOI,XOJ,AAYI,BAYI,CAYI,ABYI,BBYI,CBYI,AAZJ,BADET 20
2ZJ,CAZJ,ABZJ,BBZJ,CBZJ,AYTI,AZTI,BYTI,BZTI,NSYMQD,XTI,XTJ,NQ,XYZNQDET 30
3,XZZNQ)
C
C *****
C
C
C
C ESTABLISHES THE QUADRANT THAT THE POINT IS IN, AND RETURNS THE
C VALUFS OF THE CONSTANTS IN THE WALL CONTCUR EQUATIONS
C
C *****
C
C LOGICAL XSIGN,YSIGN
C COMMON /SGN/ XSIGN,YSIGN
C COMMON /MIDLE/ XY2(4),XZ2(4)
C COMMON /COORD/ XO(4),RC(4),AK(4),XT(4),YT(4),AN(4),BN(4),CN(4),DN(4)DET 140
14),EN(4),AAY(4),BAY(4),CAY(4),ABY(4),BBY(4),CBY(4),AAZ(4),BAZ(4),CDET 150
2AZ(4),ABZ(4),BBZ(4),CBZ(4),AYTEST(4),AZTEST(4),BYTEST(4),BZTEST(4)DET 160
3,SYMMY(4)
C DATA NQ1/0/
C
C LOGIC TO DETERMINE THE QUADRANT
C NOTE HERE THAT THE COORDINATE X AND Y HAVE BEEN USED FOR THE CCORD-
C INCTES X2 AND X3.
C
C XSIGN=X.LT.0.
C YSIGN=Y.LT.0.
C IF (XSIGN) GO TO 10
C GO TO 40
C
C IF (YSIGN) GO TO 20
C GO TO 30
C
C I=3
C J=4
C NQ=3
C GO TO 60
C
C I=1
C J=4
C NQ=4
C GO TO 60
C
C IF (YSIGN) GO TO 50
C I=1
C J=2
C NQ=1
C GO TO 60
C
C I=3
C J=2
C NQ=2
C
C CONTINUE
C NSYMQD=SYMMY(NQ)

```

C		DET 550
C	RETURN ONLY THE CONSTANTS FOR ONE QUADRANT IF CONTOUR IS SYMMETRIC	DET 560
C		DET 570
	GO TO (80,70), NSYMQD	DET 580
70	NSYMQD=2	DET 590
	X=ABS(X)	DET 600
	Y=ABS(Y)	DET 610
	XDN=ABS(XDN)	DET 620
	YDN=ABS(YDN)	DET 630
	IF (NQ.EQ.NQ1) RETURN	DET 640
	XY2NQ=XY2(NQ)	DET 650
	XZ2NQ=XZ2(NQ)	DET 660
	ANI=AN(I)	DET 670
	BNI=BN(I)	DET 680
	CNI=CN(I)	DET 690
	ONI=ON(I)	DET 700
	ENI=EN(I)	DET 710
	ANJ=AN(J)	DET 720
	BNJ=BN(J)	DET 730
	CNJ=CN(J)	DET 740
	ONJ=ON(J)	DET 750
	ENJ=EN(J)	DET 760
	XTI=XT(I)	DET 770
	XIJ=XI(J)	DET 780
	AKI=AK(I)	DET 790
	AKJ=AK(J)	DET 800
	RCI=RC(I)	DET 810
	RCJ=RC(J)	DET 820
	XOI=XO(I)	DET 830
	XOJ=XO(J)	DET 840
	AAYI=AAY(NQ)	DET 850
	BAYI=BAY(NQ)	DET 860
	CAYI=CAY(NQ)	DET 870
	ABYI=ABY(NQ)	DET 880
	BBYI=BBY(NQ)	DET 890
	CBYI=CBY(NQ)	DET 900
	AAZJ=AAZ(NQ)	DET 910
	BAZJ=BAZ(NQ)	DET 920
	CAZJ=CAZ(NQ)	DET 930
	ABZJ=ABZ(NQ)	DET 940
	BBZJ=BBZ(NQ)	DET 950
	CBZJ=CBZ(NQ)	DET 960
	AYTI=AYTEST(NQ)	DET 970
	AZTJ=AZTEST(NQ)	DET 980
	BYTI=BYTEST(NQ)	DET 990
	BZTJ=BZTEST(NQ)	DET 1000
	NQ1=NQ	DET 1010
	RETURN	DET 1020
C		DET 1030
C	FOR NSYMMY = 1 THE NOZZLE IS AXISYMMETRIC	DET 1040
C		DET 1050
	ENTRY DETRM2(Y,X,YDN,XDN,ANI,BNI,CNI,ONI,ENI,ANJ,BNJ,CNJ,ONJ,ENJ,AD	DET 1060
	1KI,AKJ,RCI,RCJ,XOI,XOJ,AAYI,BAYI,CAYI,ABYI,BBYI,CBYI,AAZJ,BAZJ,CAZ	DET 1070
	2J,ABZJ,BBZJ,CBZJ,AYTI,AZTJ,BYTI,BZTJ,NSYMQD,XI,I,XIJ,NQ,XY2NQ,XZ2	DET 1080
	3)	DET 1090
C		DET 1100

80       NQ=1  
          CONTINUE  
          IF (NQ.EQ.NQ1) RETURN  
          ANI=AN(NQ)  
          BNI=BN(NQ)  
          CNI=CN(NQ)  
          DNI=DN(NQ)  
          ENI=EN(NQ)  
          XTI=XT(NQ)  
          AKI=AK(NQ)  
          RCI=RC(NQ)  
          XDI=XD(NQ)  
          NSYMQD=1  
          NQ1=NQ  
          RETURN  
          END

DET1110  
DET1120  
DET1130  
DET1140  
DET1150  
DET1160  
DET1170  
DET1180  
DET1190  
DET1200  
DET1210  
DET1220  
DET1230  
DET1240  
DET1250  
DET1260-



```

C6=CC
C7=C5*P1/S
C8=C6*P2
DO 40 N=1,25
  XL=Y/S+C1
  FY=C2*XL**EZ+C3*Y**EY-C4
  DFY=C5*XL**P1+C6*Y**P2
  YNOW=Y-FY/DFY
  DIFF=ABS(YNOW-Y)/Y
  Y=YNOW
  IF (DIFF.LT.ERROR) GO TO 50
40  CONTINUE
    CALL ERRORS (16)
50  Y1=Y
    X1=Y1/S+C1
60  RETURN
    END

```

```

ITE 550
ITE 560
ITE 570
ITE 580
ITE 590
ITE 600
ITE 610
ITE 620
ITE 630
ITE 640
ITE 650
ITE 660
ITE 670
ITE 680
ITE 690
ITE 700
ITE 710-

```

```

$IBFTC NSOLV
      SUBROUTINE NSOLV (A,B,X0,Y0,XDN,YDN,EX,EY,X1,Y1,NSOLZ,NSOLY,DADX,DNSO  10
      1BDX,DEXDX,DEYDX) NSO 20
C
C ***** NSO 30
C NSO 40
C ***** NSO 50
C USED TO SOLVE DIRECTLY FOR THE INTERSECTION WITH THE CONTOUR WHEN NSO 60
C THE SUPER-ELLIPTICAL EXPONENTS ARE 2.0 AND TO COMPUTE THE NORMALS NSO 70
C ***** NSO 80
C ***** NSO 90
C NSO 100
      LOGICAL XSIGN,YSIGN NSO 110
      COMMON /SGN/ XSIGN,YSIGN NSO 120
      COMMON /NSLV/ XNORM,YNORM,ZNORM NSO 130
      DATA DELL/.00000001/ NSO 140
      N=1 NSO 150
      T1=1. NSO 160
      T2=1. NSO 170
      IF (X0.LE.DELL) GO TO 180 NSO 180
      IF (Y0.LE.DELL) GO TO 160 NSO 190
      IF (XDN.LE.DELL) GO TO 170 NSO 200
      IF (YDN.LE.DELL) GO TO 150 NSO 210
      GO TO (10,20), NSOLZ NSO 220
10  GO TO (190,20), NSOLY NSO 230
20  CALL ITER (A,B,X0,Y0,XDN,YDN,EX,EY,X1,Y1) NSO 240
30  CONTINUE NSO 250
      IF (XSIGN) GO TO 40 NSO 260
      GO TO 50 NSO 270
C NSO 280
40  X1=-X1 NSO 290
      A=-A NSO 300
      DADX=-DADX NSO 310
50  IF (YSIGN) GO TO 60 NSO 320
      GO TO 70 NSO 330
C NSO 340
60  Y1=-Y1 NSO 350
      B=-B NSO 360
      DBDX=-DBDX NSO 370
70  X1A=X1/A NSO 380
      Y1B=Y1/B NSO 390
      GO TO (80,90,100), N NSO 400
80  X2A=X1A NSO 410
      Y2B=Y1B NSO 420
      GO TO 110 NSO 430
C NSO 440
90  X2A=1. NSO 450
      T1=0. NSO 460
      Y2B=1. NSO 470
      GO TO 110 NSO 480
C NSO 490
100 Y2B=1. NSO 500
      T2=0. NSO 510
      X2A=1. NSO 520
C NSO 530
C CALCULATE NORMALS TO SURFACE NSO 540

```

C		NS0 550
110	CONTINUE	NS0 560
	XNORM=T1*(X1A**EX)*((-EX/A)*DADX+ALOG(X2A)*DEXDX)+T2*(Y1B**EY)*((-NS0 570	
	1EY/B)*DBDX+ALOG(Y2B)*DEYDX)	NS0 580
	YNORM=EY*((Y1B)**(EY-1.))/B	NS0 590
	ZNORM=FX*((X1A)**(EX-1.))/A	NS0 600
C		NS0 610
C	NORMALIZE DIRECTION RATIOS	NS0 620
C		NS0 630
	D=SQRT(XNORM**2+YNORM**2+ZNORM**2)	NS0 640
	XNORM=XNORM/D	NS0 650
	YNORM=YNORM/D	NS0 660
	ZNORM=ZNORM/D	NS0 670
	IF (XSIGN) GO TO 120	NS0 680
	GO TO 130	NS0 690
C		NS0 700
120	A=-A	NS0 710
	DADX=-DADX	NS0 720
130	IF (YSIGN) GO TO 140	NS0 730
	GO TO 200	NS0 740
C		NS0 750
140	B=-B	NS0 760
	DBDX=-DBDX	NS0 770
	GO TO 200	NS0 780
C		NS0 790
C	CASES FOR WHICH EITHER XDN OR YDN ARE ZERO	NS0 800
C		NS0 810
150	Y1=0	NS0 820
	X1=A*(1.-(Y1/B)**EY)**(1./EX)	NS0 830
	GO TO 30	NS0 840
C		NS0 850
160	Y1=0.	NS0 860
	X1=A	NS0 870
	N=2	NS0 880
	GO TO 30	NS0 890
C		NS0 900
170	X1=X0	NS0 910
	Y1=B*(1.-(X1/A)**EX)**(1./EY)	NS0 920
	GO TO 30	NS0 930
C		NS0 940
180	X1=0.	NS0 950
	Y1=B	NS0 960
	N=2	NS0 970
	GO TO 30	NS0 980
C		NS0 990
C	SOLVE DIRECTLY FOR POINTS WHEN EY=EZ=2	NS01000
C		NS01010
190	S=YDN/XDN	NS01020
	AG=(A**2)**2+B**2	NS01030
	BG=(A**2)*2.*S*(Y0-X0*S)	NS01040
	CG=(A**2)*((Y0-S*X0)**2-B**2)	NS01050
	X1=(-BG+SQRT(BG**2-4.*AG*CG))/(2.*AG)	NS01060
	Y1=Y0+S*(X1-X0)	NS01070
	GO TO 30	NS01080
C		NS01090
200	RETURN	NS01100
	END	NS01110-

SUBFC REFLECT		
	SUBROUTINE REFLECT (K)	REF 10
C		REF 20
C	*****	REF 30
C		REF 40
C	CONTROLS LOGIC OF REFLECTING POINTS AND PROPERTIES WITH RESPECT TO	REF 50
C	PLANES OF SYMMETRY	REF 60
C		REF 70
C	*****	REF 80
C		REF 90
	COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,MP,NT,II,JJ,L,LL	REF 100
	INSTART,DELX,ODELX,KK,XI2,XMAX,ND	REF 110
	INTEGER PRINT1,PRINT2	REF 120
	GO TO (10,30,60), ICLASS	REF 130
10	NP1=NP-1	REF 140
	DO 20 I=1,MP	REF 150
	CALL REFXY (K,I,MP1)	REF 160
20	CALL REFKS (K,I,I+1)	REF 170
	CALL REFKS (K,MP1,MP+1)	REF 180
	CALL REFXY (K,MP+1,MP1)	REF 190
	CALL REFXY (K,I,MP-2)	REF 200
	CALL REFKS (K,I,3)	REF 210
	RETURN	REF 220
30	NP2=NP+2	REF 230
	DO 40 I=1,MP	REF 240
	CALL REFXY (K,I,MP-1)	REF 250
40	CALL REFXY (K,I,MP-2)	REF 260
	DO 50 I=1,MP2	REF 270
	CALL REFKZ (K,MP-1,I)	REF 280
50	CALL REFKZ (K,MP-2,I)	REF 290
	RETURN	REF 300
60	NP2=NP+2	REF 310
	DO 70 I=1,NT	REF 320
	CALL REFXY (K,I,MP-1)	REF 330
70	CALL REFXY (K,I,MP-2)	REF 340
	RETURN	REF 350
	END	REF 360-



```

      ORIGIN      A
      SUBFC Spline
      SUBROUTINE Spline (KNOT,XK,VALUE,COEF)
C
C *****
C
C GIVEN THE ORDS VALUE(I,1) AT KNOTS XK(I) AND SLOPES VALUE(I,2) AT
C THE FIRST AND LAST KNOTS, THIS SUBR. FINDS THE CUBIC SPLINE WHICH
C INTERPOLATES AT THE KNOTS W.R.T. ABOVE VALUES. THE INTERP. IS IN THE
C SENSE THAT SLOPE VALUES OF THE SPLINE ARE COMPLETED AT EACH OF THE
C GIVEN KNOTS.
C
C *****
C
      DIMENSION D(30), DIAG(30), VALUE(30,2), XK(30), COEF(4,30)
      KNM1=KNOT-1
      KNM2=KNOT+2
      DO 20 M=1,KNM1
        D(M)=XK(M+1)-XK(M)
10    DIAG(M)=(VALUE(M+1,1)-VALUE(M,1))/D(M)
      DO 20 M=2,KNM1
        VALUE(M,2)=3.*(D(M-1)*DIAG(M)+D(M)*DIAG(M-1))
20    DIAG(M-1)=2.*(D(M)+D(M-1))
        VALUE(2,2)=VALUE(2,2)-D(2)*VALUE(1,2)
        VALUE(KNM1,2)=VALUE(KNM1,2)-D(KNM2)*VALUE(KNOT,2)
        IF (KNOT.EQ.3) GO TO 40
      DO 30 M=2,KNM2
        G=-D(M+1)/DIAG(M-1)
        DIAG(M)=DIAG(M)+G*D(M-1)
30    VALUE(M+1,2)=VALUE(M+1,2)+G*VALUE(M,2)
40    VALUE(KNM1,2)=VALUE(KNM1,2)/DIAG(KNM2)
        IF (KNOT.EQ.3) GO TO 60
      DO 50 M=2,KNM2
        NJ=KNOT-M
50    VALUE(NJ,2)=(VALUE(NJ,2)-D(NJ-1)*VALUE(NJ+1,2))/DIAG(NJ-1)
60    CONTINUE
      DO 70 J=2,KNOT
        DX=XK(J)-XK(J-1)
        COEF(1,1)=VALUE(J-1,1)
        COEF(2,1)=VALUE(J-1,2)
        COEF(3,1)=(VALUE(J,1)-COEF(1,1))/DX
        COEF(4,1)=COEF(2,1)+VALUE(J,2)-2.*COEF(3,1)
        COEF(3,1)=(COEF(3,1)-COEF(4,1)-COEF(2,1))/DX
70    COEF(4,1)=COEF(4,1)/DX
      RETURN
      END

```

SIBFIC MACHP		MAC 10
SUBROUTINE MACHP (H,PT,H,P,Q)		MAC 20
C *****		MAC 30
C		MAC 40
C THE PRESSURE AND VELOCITY ARE FOUND FOR A SPECIFIED MACH NO. USING		MAC 50
C ARCSB1 BY THE NEWTON RAPHSON ITERATION SCHEME		MAC 60
C *****		MAC 70
C		MAC 80
C		MAC 90
REAL H,M1,M2		MAC 100
K=0		MAC 110
P1=PT*(1.0+0.1*M**2)**(-6)*(1.0-0.1/M**2)		MAC 120
P2=P1*0.99		MAC 130
CALL ARCSB1 (P1,PT,H,A,RO,QS)		MAC 140
P1=SQRT(QS)/A		MAC 150
CALL ARCSB1 (P2,PT,H,A,RO,QS)		MAC 160
M2=SQRT(QS)/A		MAC 170
DO 30 N=1,50		MAC 180
P=P2+(M-M2)*(P2-P1)/(M2-M1)		MAC 190
IF (P) 10,10,20		MAC 200
10 P=P2*0.9		MAC 210
20 CALL ARCSB1 (P,PT,H,A,RO,QS)		MAC 220
K=K+1		MAC 230
P1=P2		MAC 240
M1=M2		MAC 250
P2=P		MAC 260
M2=SQRT(QS)/A		MAC 270
IF (ABS((P2-P1)/P2).LT.1.0E-07) GO TO 40		MAC 280
30 CONTINUE		MAC 290
C		MAC 300
C FAILED TO CONVERGE IN 50 ITERATIONS		MAC 310
C		MAC 320
CALL ERRORS (3)		MAC 330
40 C=SQRT(QS)		MAC 340
RETURN		MAC 350
END		MAC 360-

81BFTC SOURCE	
SUBROUTINE SOURCE (ROV,HI,PT1,PRESS,Q)	SOU 70
C	SOU 20
C	SOU 30
C	SOU 40
C	SOU 50
C	SOU 60
C	SOU 70
C	SOU 80
C	SOU 90
C	SOU 100
COMMON /AR01/ GAMMA,RCAS,GAM1,GAM2,GAM3,GAM4,GAM5,PTAB(30),ACC(4,3	SOU 110
10),ROCO(4,30),TCO(4,30),QSCO(4,30),MFOE,NTHERM,1,PSOURC	SOU 120
P1=PSOURC	SOU 130
P2=P1*0.99	SOU 140
CO 60 N=1,50	SOU 150
CALL AR05B1 (P1,PT1,HI,A,RO1,QS1)	SOU 160
CALL AR05B1 (P2,PT1,HI,A,RO2,QS2)	SOU 170
ROV1=RO1*SQRT(QS1)	SOU 180
ROV2=RO2*SQRT(QS2)	SOU 190
DELP=(ROV-ROV2)/(ROV1-ROV2)*(P1-P2)	SOU 200
IF (ABS(DELP/P2)-0.2) 10,10,20	SOU 210
10        IF (ABS(DELP/P2).LT.1.0E-07) GO TO 70	SOU 220
GO TO 50	SOU 230
C	SOU 240
20        P1=P2	SOU 250
IF (DELP) 30,30,40	SOU 260
30        P2=P2*0.9	SOU 270
GO TO 60	SOU 280
C	SOU 290
40        P2=P2*1.1	SOU 300
GO TO 60	SOU 310
C	SOU 320
50        P1=P2	SOU 330
P2=P2+DELP	SOU 340
60        CONTINUE	SOU 350
C	SOU 360
C	SOU 370
C	SOU 380
WRITE (6,80) P1,P2,ROV,ROV1,ROV2,PSOURC	SOU 390
CALL ERRORS (5)	SOU 400
70    Q=SQRT(QS2)	SOU 410
PRESS=P2	SOU 420
PSOURC=P2	SOU 430
RETURN	SOU 440
C	SOU 450
C	SOU 460
80    FORMAT (1H0,6E15.7)	SOU 470
END	SOU 480-

```

$18FTC INVALS
SUBROUTINE INVALS (I,J)
C
C *****
C
C CALCULATES INITIAL SURFACE PROPERTIES AT THE POINT (I,J). FOUR
C OPTIONS ARE AVAILABLE AND ARE SELECTED BY THE PARAMETER IVSTYP WHICH
C CAN HAVE THE VALUES 1, 2, 3 OR 4 CORRESPONDING TO
C 1 - UNIFORM MOMENTROPIC FLOW AT THE VALUES SPECIFIED AT THE
C THE CENTER POINT OF THE INITIAL VALUE SURFACE
C 2 - MOMENTROPIC SOURCE FLOW SPECIFIED BY THE REFERENCE POINT
C PROPERTIES AT THE CENTER POINT OF THE INITIAL VALUE SURFACE
C 3 - AXISYMMETRIC NONMOMENTROPIC FLOW SPECIFIED BY TABULAR INPUT
C 4 - LINKAGE TO A USER SUPPLIED SUBROUTINE CALLED IVSUB(I,J)
C
C *****
C
COMMON /SOLUTN/ Y(2,19,19),Z(2,19,19),L(2,19,19),V(2,19,19),h(2,19,19)
1,19),P(2,19,19),PT(19,19),H(19,19),K(19,19),K(19,19)
COPKUH /ARG1/ GAMMA,RGAS,GAM1,GAM2,GAM3,GAM4,GAM5,PTAB(30),ACO(4,3)
10),ROCO(4,30),TCO(4,30),QSCO(4,30),NFDE,NTHETA,I111,PSOURC
C
COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,MP,MT,JI,JJ,LL,LL
INSTART,DELX,ODELX,KK,X(2),XMAX,NO
COMMON /LCNST/ P1,DRAD,BTU,G,BTUOG
COMMON /IVS/ XSORC,YSORC,ZSORC,XIVS,YCIVS,ZCIVS,MCIVS,PHICIV,THSCIV
1V,PTCIVS,MCIVS,RIVS,MIVS,THETIV,PSIIV,PTIVS,HIVS,XPSORC,YPSORC,ZPSIV
2CRC,ALPSRC,BETSRC
COMMON /PLANES/ NPDS,NX1,NY1,NZ1,NX2,NY2,NZ2
COMMON /WALSU/ YAXIS,ZAXIS,XT(4),RT(4),RC(4),THETAT(4),XE(4),RE(4)
1,THETA(4),NSYMMY,XY1(4),EXPY1(4),XY2(4),EXPY2(4),DEDX2(4),EXPY3(4)
24),XZ1(4),EXPZ1(4),XZ2(4),EXPZ2(4),DEDX2(4),EXPZ3(4),XY3(4),XZ3(4)
3)
DIMENSION RIVS(30), MIVS(30), THETIV(30), PTIVS(30,2), HIVS(30,2),
1 PSIIV(30)
DIMENSION UXIVS(30,2), URIVS(30,2), PIVS(30,2), URCO(4,30), URCO(4,30)
1,30), PCO(4,30), MCO(4,30), PTCO(4,30), UTCO(4,30), UTIVS(30,2)
REAL MCIVS,MIVS,NX1,NY1,NZ1,NX2,NY2,NZ2,NX,NY,NZ
INTEGER PRINT1,PRINT2
GO TO (10,20,30,70), IVSTYP
C
C UNIFORM MOMENTROPIC FLOW
C
C
10 U(1,I,J)=U1
V(1,I,J)=V1
W(1,I,J)=W1
P(1,I,J)=P1
H(1,J)=HCIVS
PT(1,J)=PTCIVS
GO TO 80
C
C MOMENTROPIC SOURCE FLOW
C
C
20 RSQ=(XIVS-XSORC)**2+(Y(1,I,J)-YSORC)**2+(Z(1,I,J)-ZSORC)**2
ROF=SOURF/RSQ

```

CALL SOURCE (ROV,MCIVS,PTCIVS,P(1,1,1),Q)	INV 550
RP=SQRT(RSQ)	INV 560
U(1,1,J)=Q*(XIVS-XSORC)/RP	INV 570
V(1,1,J)=Q*(Y(1,1,J)-YSORC)/RP	INV 580
W(1,1,J)=Q*(Z(1,1,J)-ZSORC)/RP	INV 590
H(1,J)=MCIVS	INV 600
P(1,J)=PTCIVS	INV 610
GO TO 80	INV 620
C	INV 630
C AXISYMMETRIC NONHUMENTROPIC FLOW	INV 640
C	INV 650
C CALCULATE RADIUS FROM AXIS	INV 660
C	INV 670
30 RPI=SQRT((Y(1,1,J)-YCIVS)**2+(Z(1,1,J)-ZCIVS)**2)	INV 680
DO 40 K1=2,NIVPTS	INV 690
K=K1	INV 700
DR=RPI-RIVS(K1)	INV 710
IF (DR) 50,50,40	INV 720
40 CONTINUE	INV 730
C	INV 740
C TEST TO SEE IF RANGE OF TABULAR DATA HAS BEEN EXCEEDED	INV 750
C	INV 760
IF (ABS(DR).LE.1.0E-05) GO TO 50	INV 770
CALL ERRORS (6)	INV 780
C	INV 790
C USE CUBIC SPLINE COEFS. TO INTERP. FOR PROPERTIES	INV 800
C	INV 810
30 RP=RPI-RIVS(K-1)	INV 820
U(1,1,J)=UXCO(1,K)+UXCO(2,K)*RP+UXCO(3,K)*RP**2+UXCO(4,K)*RP**3	INV 830
P(1,1,J)=PCO(1,K)+PCO(2,K)*RP+PCO(3,K)*RP**2+PCO(4,K)*RP**3	INV 840
P(1,1,J)=PTCO(1,K)+PTCO(2,K)*RP+PTCO(3,K)*RP**2+PTCO(4,K)*RP**3	INV 850
H(1,J)=HCO(1,K)+HCO(2,K)*RP+HCO(3,K)*RP**2+HCO(4,K)*RP**3	INV 860
IF (RPI.LE.1.0E-07) GO TO 60	INV 870
UR=URCO(1,K)+URCO(2,K)*RP+URCO(3,K)*RP**2+URCO(4,K)*RP**3	INV 880
UT=UTCO(1,K)+UTCO(2,K)*RP+UTCO(3,K)*RP**2+UTCO(4,K)*RP**3	INV 890
V(1,1,J)=(UR*(Y(1,1,J)-YCIVS)-UT*(Z(1,1,J)-ZCIVS))/RPI	INV 900
W(1,1,J)=(UR*(Z(1,1,J)-ZCIVS)+UT*(Y(1,1,J)-YCIVS))/RPI	INV 910
GO TO 80	INV 920
C	INV 930
60 V(1,1,J)=0.0	INV 940
W(1,1,J)=0.0	INV 950
GO TO 80	INV 960
C	INV 970
C USER SUPPLIED INITIAL VALUE SUBROUTINE	INV 980
C	INV 990
TO III=I	INV1000
JJJ=J	INV1010
CALL IVSUB (III,JJJ)	INV1020
80 RETURN	INV1030
ENTRY INVAL2	INV1040
C	INV1050
C INITIALIZE SUBROUTINE INVALS AND PRINT OUT APPROPRIATE PARAMETERS	INV1060
C THESE LIMITS WILL DEPEND ON THE DIMENSIONS OF COMMON /SOLUTN/ AND	INV1070
C /XAGLT/	INV1080
C	INV1090
IF (NPOS.LE.1.AND.NP.GT.10) NP=10	INV1100

	IF (NPDS.GT.1.AND.NP.GT.17) NP=1/	INV1110
	NT=2*NP-1	INV1120
	WRITE (6,200)	INV1130
	WRITE (6,210)	INV1140
C		INV1150
C	INITIALIZE WHICHEVER OPTION 1, 2, 3 OR 4 IS SELECTED	INV1160
C		INV1170
	GO TO (90,100,110,160), IVSTYP	INV1180
C		INV1190
C	UNIFORM MOMENTROPIC FLOW	INV1200
C		INV1210
90	IF (MCIVS.LE.1.0) GO TO 180	INV1220
	WRITE (6,220) XIYS,MCIVS,THECIV,PHICIV,PTCIVS,MCIVS	INV1230
	PTCIVS=PTCIVS*144.0	INV1240
	MCIVS=MCIVS*BTUDG	INV1250
	CALL MACHP (MCIVS,PTCIVS,MCIVS,P1,Q)	INV1260
	THECIV=THECIV*DRAD	INV1270
	PHICIV=PHICIV*DRAD	INV1280
	U1=Q*COS(PHICIV)*COS(THECIV)	INV1290
	V1=Q*COS(PHICIV)*SIN(THECIV)	INV1300
	W1=Q*SIN(PHICIV)	INV1310
	X(1)=XIYS	INV1320
	GO TO 170	INV1330
C		INV1340
C	SPHERICAL MOMENTROPIC SOURCE	INV1350
C		INV1360
100	YSORC=YAXIS	INV1370
	ZSORC=ZAXIS	INV1380
	XIVS=XT(1)+RC(1)*SIN(ALPSRC*DRAD)	INV1390
	X(1)=XIVS	INV1400
	XSORC=XIVS-(RT(1)+RC(1)*(1.0-COS(ALPSRC*DRAD)))/TAN(ALPSRC*DRAD)	INV1410
	IF (MCIVS.LE.1.0) GO TO 180	INV1420
	WRITE (6,230) ALPSRC,XSORC,YSORC,ZSORC,XIVS,YCIVS,ZCIVS,MCIVS,PTCIVS,MCIVS	INV1430
	PTCIVS=PTCIVS*144.0	INV1440
	MCIVS=MCIVS*BTUDG	INV1450
	RSQ=(XIVS-XSORC)**2	INV1460
	RP=SQRT(RSQ)	INV1470
	CALL MACHP (MCIVS,PTCIVS,MCIVS,PCIVS,QSIVS)	INV1480
	CALL ARDSB1 (PCIVS,PTCIVS,MCIVS,ACIVS,RCIVS,QSIVS)	INV1490
	SOURF=RSQ*RCIVS*SQRT(2.5IVS)	INV1500
	PSOURC=PCIVS	INV1510
	GO TO 170	INV1520
C		INV1530
C	TABULAR AXISYMMETRIC NONMOMENTROPIC FLOW	INV1540
C		INV1550
110	YP=1.0+YAXIS	INV1560
	ZP=ZAXIS	INV1570
	WRITE (6,240)	INV1580
	AX=0.0	INV1590
	AY=1.0	INV1600
	AZ=0.0	INV1610
	X(1)=XIVS	INV1620
C		INV1630
C	FIND RADIUS OF CONTOUR(MUST BE AXISYMMETRIC)	INV1640
C		INV1650
		INV1660

CALL WALSUB (XIVS,YP,ZP,NX,NY,NZ)	INV1670
DO 140 K=1,30	INV1680
NIVPTS=K	INV1690
WRITE (6,260) RIVS(K),MIVS(K),THETIV(K),PSIIV(K),PTIVS(K,1),HIVS(K,1)	INV1700
1  S(K,1)	INV1710
PTIVS(K,1)=PTIVS(K,1)*144.0	INV1720
HIVS(K,1)=HIVS(K,1)*BTUDG	INV1730
C	INV1740
C  MACH NUMBER CN I.V.S. MUST BE EVERYWHERE GREATER THAN ONE	INV1750
IF (MIVS(K).LE.1.0) GO TO 180	INV1770
CALL MACHP (MIVS(K),PTIVS(K,1),HIVS(K,1),PIVS(K,1),Q)	INV1780
C	INV1790
C  CANNOT HAVE PLANES OF SYMMETRY IF ANY PSI IS GREATER THAN ZERO	INV1800
C	INV1810
IF (PSIIV(K).GT.0.0.AND.NPOS.GT.0) GO TO 190	INV1820
PSIIV(K)=PSIIV(K)*DRAD	INV1830
THETIV(K)=THETIV(K)*DRAD	INV1840
UXIVS(K,1)=Q*COS(THETIV(K))*COS(PSIIV(K))	INV1850
UTIVS(K,1)=Q*COS(THETIV(K))*SIN(PSIIV(K))	INV1860
URIVS(K,1)=Q*SIN(THETIV(K))	INV1870
IF (RIVS(K)-YP) 120,150,120	INV1880
120  IF (ABS(RIVS(K)-YP).LE.0.0001) GO TO 150	INV1890
IF (RIVS(K)-YP) 140,150,130	INV1900
C	INV1910
C  WARNING IF LAST POINT OF TABULAR VALUES IS NOT ON WALL	INV1920
C	INV1930
130  CALL ERRORS (7)	INV1940
GO TO 150	INV1950
C	INV1960
140  CONTINUE	INV1970
C	INV1980
C  ESTIMATE DERIVATIVES AT ENDS OF CURVES BY FINITE DIFFERENCE APPROX.	INV1990
C	INV2000
150  UXIVS(1,2)=0.0	INV2010
UTIVS(1,2)=0.0	INV2020
URIVS(1,2)=0.0	INV2030
PIVS(1,2)=0.0	INV2040
PTIVS(1,2)=0.0	INV2050
HIVS(1,2)=0.0	INV2060
DELR=RIVS(NIVPTS)-RIVS(NIVPTS-1)	INV2070
UXIVS(NIVPTS,2)=(UXIVS(NIVPTS,1)-UXIVS(NIVPTS-1,1))/DELR	INV2080
UTIVS(NIVPTS,2)=(UTIVS(NIVPTS,1)-UTIVS(NIVPTS-1,1))/DELR	INV2090
URIVS(NIVPTS,2)=(URIVS(NIVPTS,1)-URIVS(NIVPTS-1,1))/DELR	INV2100
PIVS(NIVPTS,2)=(PIVS(NIVPTS,1)-PIVS(NIVPTS-1,1))/DELR	INV2110
PTIVS(NIVPTS,2)=(PTIVS(NIVPTS,1)-PTIVS(NIVPTS-1,1))/DELR	INV2120
HIVS(NIVPTS,2)=(HIVS(NIVPTS,1)-HIVS(NIVPTS-1,1))/DELR	INV2130
CALL SPLINE (NIVPTS,RIVS,UXIVS,UXCD)	INV2140
CALL SPLINE (NIVPTS,RIVS,UTIVS,UTCD)	INV2150
CALL SPLINE (NIVPTS,RIVS,URIVS,URCD)	INV2160
CALL SPLINE (NIVPTS,RIVS,PIVS,PCL)	INV2170
CALL SPLINE (NIVPTS,RIVS,PTIVS,PTCD)	INV2180
CALL SPLINE (NIVPTS,RIVS,HIVS,HCD)	INV2190
GO TO 170	INV2200
C	INV2210
160  WRITE (6,250)	INV2220
CALL IVS82	INV2230

	X(1)=XIVS	INV2240
170	RETURN	INV2250
C		INV2260
C	ERROR RETURN IF A MACH NO. LESS THAN ONE IS FOUND	INV2270
C		INV2280
180	CALL ERRORS (8)	INV2290
C		INV2300
C	ERROR RETURN FOR INCOMPATIBLE DATA	INV2310
C		INV2320
190	CALL ERRORS (9)	INV2330
	RETURN	INV2340
C		INV2350
C		INV2360
200	FORMAT (1H0)	INV2370
210	FORMAT (1H0,5X,28HTYPE OF INITIAL DATA SURFACE)	INV2380
220	FORMAT (1H0,10X,85HTHE FOLLOWING VALUES ARE CONSTANT OVER THE ENTIRE INITIAL DATA SURFACE LOCATED AT X =,F9.4,5H (IN)/1H0,10X,3HH =,INV2390	
	2F8.4,4X,7HTHETA =,F7.2,1X,5H(DEG),4X,5HPI =,F7.2,1X,5H(DEG),4X,4HINV2410	
	3PT =,F9.2,1X,11H(LBF/IN**2),4X,3HH =,F10.2,1X,9H(BTU/LBM))	INV2420
230	FORMAT (1H0,10X,115HSOURCE FLOW IS USED TO ESTABLISH THE INITIAL VALUES. THE SOURCE ANGLE IS SPECIFIED AND THE SOURCE POINT IS LOCATED	INV2430
	2TED/1H0,10X,110HON THE NOZZLE AXIS SUCH THAT THE INITIAL FLOW IS TANGENT	INV2440
	TO THE NOZZLE WALL. THE PROPERTIES OF THE SOURCE ARE/1H0,110H	INV2450
	40X,95HESTABLISHED BY SPECIFICATION OF THE PROPERTIES AT THE AXIAL	INV2460
	5POINT OF THE INITIAL VALUE SURFACE./1H0,10X,12HSOURCE POINT/1H0,10H	INV2470
	6X,14HSOURCE ANGLE =,F1.3,5H (DEG),2X,3HH =,F10.4,5H (IN),2X,3HY =	INV2480
	7,F10.4,5H (IN),2X,3HZ =,F10.4,5H (IN),/1H0,10X,15HREFERENCE POINT/INV2490	
	81H0,10X,3HX =,F10.4,5H (IN),2X,3HY =,F10.4,5H (IN),2X,3HZ =,F10.4,INV2510	
	95H (IN)/1H0,10X,3HH =,F10.4,4X,4HPT =,F10.2,11H(LBF/IN**2),2X,3HH	INV2520
	*=,F12.1,9H(BTU/LBM))	INV2530
240	FORMAT (1H0,10X,108HTHE INITIAL VALUES ARE AXISYMMETRIC AND ARE SPECIFIED BY TABULAR INPUT AS FUNCTIONS OF THE RADIAL COORDINATE/1H0,10X,10H	INV2540
	2,10X,10HRADIUS(IN),2X,8HMACH NO.,2X,10HTHETA(DEG),2X,8HPSI(DEG),1X,10H	INV2550
	3,13HPT(LBM/IN**2),1X,10HH(BTU/LBM))	INV2560
250	FORMAT (1H0,10X,105HTHE VALUES OF THE DEPENDENT VARIABLES ARE DETERMINED BY MEANS OF A USER SUPPLIED SUBROUTINE CALLED INVALS)	INV2570
		INV2580
260	FORMAT (1H ,10X,F9.4,2X,F8.4,3X,F7.3,4X,F7.3,4X,F8.2,7X,F8.2)	INV2590
	END	INV2600
		INV2610-

```

$IBFIC IVSUB
SUBROUTINE IVSUB (I,J)
C
C *****
C
C THIS SUBROUTINE MAY BE REPLACED BY A USER SUPPLIED SUBROUTINE IN
C ORDER TO GENERATE SPECIALIZED TYPES OF INITIAL DATA SURFACES
C IN THIS PARTICULAR SUBROUTINE THE IVS PROPERTIES ARE CALCULATED
C BY SUPERIMPOSING THE FLOW FROM TWO HOMETROPIC SPHERICAL SOURCE
C FLOWS -- AN APPROXIMATION FOR A SKEWED INLET FLOW
C
C *****
C
COMMON /SOI,UTN/ Y(2,19,19),Z(2,19,19),U(2,19,19),V(2,19,19),W(2,19,19),P(2,19,19),PT(19,19),H(19,19),KLASS(19,19)
COMMON /ARO1/ GAMMA,RGAS,GAM1,GAM2,GAM3,GAM4,GAM5,PTAB(30),ACO(4,30),ROCO(4,30),TCO(4,30),QSCO(4,30),NFUE,NTHERM,IIII,PSOURC
COMMON /CCNST/ PI,DRAD,BTU,G,BTUOG
COMMON /IVS/ XSORC,YSORC,ZSORC,XIVS,YCIVS,ZCIVS,MCIVS,PHICIV,THECIVS
1V,PTCIVS,HCIVS,RIVS,MIVS,THETIV,PSIIV,PTIVS,HIVS,XPORC,YPSORC,ZPSIVS
2CRC,ALPSRC,BETSRC
COMMON /PLANES/ NPOS,NX1,NY1,NZ1,NX2,NY2,NZ2
COMMON /WALSB/ YAXIS,ZAXIS,XT(4),RT(4),RC(4),THETAT(4),XE(4),RE(4)
1,THETA(4),NSYMHY,XY1(4),EXPY1(4),XY2(4),EXPY2(4),DEXY2(4),EXPY3(4),EXPY3(4),XZ1(4),EXPZ1(4),XZ2(4),EXPZ2(4),DEXZ2(4),EXPZ3(4),XY3(4),XZ3(4)
3)
DIMENSION RIVS(30), MIVS(30), THETIV(30), PTIVS(30,2), HIVS(30,2),
1 PSIIV(30)
REAL MCIVS,MIVS,NX1,NY1,NZ1,NX2,NY2,NZ2
RSQA=(XIVS-XSORC)**2+(Y(1,I,J)-YSORC)**2+(Z(1,I,J)-ZSORC)**2
RSQB=(XIVS-XSORC)**2+(Y(1,I,J)-YPSORC)**2+(Z(1,I,J)-ZPSORC)**2
ROVA=SQURF/RSQA
ROVB=SQURF/RSQB
CALL SOURCE (ROVA,HCIVS,PTCIVS,PA,QA)
CALL SOURCE (ROVB,HCIVS,PTCIVS,PB,QB)
RPA=SQRT(RSQA)
RPB=SQRT(RSQB)
UA=QA*(XIVS-XSORC)/RPA
UB=QB*(XIVS-XSORC)/RPB
VA=QA*(Y(1,I,J)-YSORC)/RPA
VB=QB*(Y(1,I,J)-YPSORC)/RPB
WA=QA*(Z(1,I,J)-ZSORC)/RPA
WB=QB*(Z(1,I,J)-ZPSORC)/RPB
R=(Y(1,I,J)-YAXIS)**2+(Z(1,I,J)-ZAXIS)**2
R=SQRT(R)
WTA=(SIN(PI/2.0*R/RO))**2
WTB=(COS(PI/2.0*R/RO))**2
UAVE=WTA*UA+WTB*UB
VAVE=WTA*VA+WTB*VB
WAVE=WTA*WA+WTB*WB
P(1,I,J)=WTA*PA+WTB*PB
QAVE=SQRT(UAVE**2+VAVE**2+WAVE**2)
CALL AROSBI (P(1,I,J),PTCIVS,HCIVS,A,RO,QSBAR)
RATIO=SQRT(QSBAR)/QAVE
U(1,I,J)=UAVE*RATIO

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V(1,I,J)=VAVE*RATIO	IVB 550
W(1,I,J)=WAVE*RATIO	IVB 560
PT(I,J)=PTCIVS	IVB 570
H(I,J)=HCIVS	IVB 580
RETURN	IVB 590
ENTRY IVSB2	IVB 600
C	IVB 610
C THIS ENTRY POINT IS CALLED IN ORDER TO PERFORM ANY INITIALIZATION	IVB 620
C CALCULATIONS FOR THE SPECIAL INITIAL VALUE SURFACE CALCULATIONS	IVB 630
C ANY INITIAL DATA PRINTOUT FOR THE SUBROUTINE IS MADE HERE	IVB 640
C	IVB 650
IF (HCIVS.LE.1.0) CALL ERRORS (8)	IVB 660
YSORC=YAXIS	IVB 670
ZSORC=ZAXIS	IVB 680
XIVS=XT(1)+RC(1)*SIN(ALPSRC*DRAD)	IVB 690
XSORC=XIVS-(RT(1)+RC(1)*(1.0-COS(ALPSRC*DRAD)))/TAN(ALPSRC*DRAD)	IVB 700
RO=RT(1)+RC(1)*(1.0-COS(ALPSRC*DRAD))	IVB 710
XPSORC=XSORC	IVB 720
ZPSORC=ZAXIS	IVB 730
YPSORC=YAXIS+(XIVS-XSORC)*TAN(BETSRC*DRAD)	IVB 740
WRITE (6,10) XIVS,YCIVS,ZCIVS,MCIVS,ALPSRC,BETSRC,PTCIVS,HCIVS,XSOI	IVB 750
10RC,YSORC,ZSORC,XSORC,YPSORC,ZPSORC	IVB 760
HCIVS=HCIVS*BTUOG	IVB 770
PTCIVS=PTCIVS*144.0	IVB 780
RSQA=(XIVS-XSORC)**2	IVB 790
CALL MACHP (MCIVS,PTCIVS,HCIVS,PCIVS,QSIVS)	IVB 800
CALL AROSBI (PCIVS,PTCIVS,HCIVS,ACIVS,RUCIVS,QSIVS)	IVB 810
SOURF=RSQA*ROCIVS*SQRT(QSIVS)	IVB 820
PSOURC=PCIVS	IVB 830
RETURN	IVB 840
C	IVB 850
C	IVB 860
10 FORMAT (1H0,10X,107HINVALS - THE INITIAL VALUES ARE CALCULATED BY	IVB 870
1SUPERIMPOSING AN AXISYMMETRIC SOURCE AND AN ASYMMETRIC SOURCE/1H0,	IVB 880
210X,34HCOORDINATES OF THE REFERENCE POINT/1HC,10X,4HX =,F9.4,5H (1V	IVB 890
3IN),4X,4HY =,F9.4,5H (IN),4X,4HZ =,F9.4,5H (IN),/1H0,10X,26HREFE	IVB 900
4RENCE POINT PROPERTIES/1H0,10X,7HMCIVS =,F8.4,4X,7HALPHA =,F6.2,6H	IVB 910
5 (DEG),4X,6HBETA =,F6.2,6H (DEG),4X,4HPT =,F9.2,11H(LBF/IN**2),4X,	IVB 920
63HH =,F9.2,9H(RTU/LBM)/1H0,10X,32HCOORDINATES OF THE SOURCE POINTS	IVB 930
7/1H0,10X,8HXSORC =,F9.4,5H (IN),4X,8HYSORC =,F9.4,5H (IN),4X,8HZ	IVB 940
8SORC =,F9.4,5H (IN),/1H0,10X,8HXPORC =,F9.4,5H (IN),4X,8HYPORC	IVB 950
9=,F9.4,5H (IN),4X,8HZPSORC =,F9.4,5H (IN)	IVB 960
END	IVB 970-

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SORIGIN      B
SIBFTC READIN
SUBROUTINE READIN
C
C *****
C
C ALL DATA NECESSARY FOR SPECIFICATION OF GAS PROPERTIES, PROGRAM
C OPTIONS, CONTOUR SHAPE AND INITIAL DATA SURFACE IS INPUT THROUGH
C NAMELIST DATA INPUT. THE NAMELISTS ARE CNTRL, WALSL, AROSL, AND
C IVSL. SOME PARAMETERS AND DATA ARE PRINTED OUT
C
C *****
C
C DIMENSION RIVS(30), HIVS(30), THETIV(30), PTIVS(30,2), HIVS(30,2),
C 1 PSIIV(30)
C COMMON /ARO1/ GAMMA, RGAS, GAM1, GAM2, GAM3, GAM4, GAM5, PTAB(30), ACO(4,3),
C 10, RUCC(4,3), TCO(4,3), QSCO(4,3), NFOE, NTHRM, IL, PSOURC
C COMMON /ARO2/ ATAB(30,2), ROTAB(30,2), TTAB(30,2), QSTAB(30,2), PTAB(30,2),
C 10
C COMMON /CNTRL/ PRINT1, PRINT2, ERROR, IVSTYP, ICLASS, NP, NT, IL, JJ, L, LL,
C INSTART, DELX, UDELX, KK, XI(2), XMAX, NO
C COMMON /CCNST/ PI, DRAD, BTU, G, BTUOG
C COMMON /IVS/ XSORC, YSORC, ZSORC, XIVS, YCIVS, ZCIVS, MCIVS, PHICIV, THECIV,
C 10, PTCIVS, HCIVS, RIVS, HIVS, THETIV, PSIIV, PTIVS, HIVS, XPSORC, YPSORC, ZPSORC,
C 20, ZCRC, ALPSRC, BETSRC
C COMMON /PLANES/ NPOS, NX1, NY1, NZ1, NX2, NY2, NZ2
C COMMON /WALSL/ YAXIS, ZAXIS, XT(4), RT(4), RC(4), THETAT(4), XE(4), RE(4),
C 1, THETA(4), NSYMMY, XY1(4), EXPY1(4), XY2(4), EXPY2(4), DEDXY2(4), EXPY3(4),
C 24, XZ1(4), EXPZ1(4), XZ2(4), EXPZ2(4), DEDXZ2(4), EXPZ3(4), XY3(4), XZ3(4),
C 3)
C COMMON /THRUT/ AREA, AREAT, FMASS, XTHR1, YTHR1, ZTHR1, XTHR, YTHR, ZTHR, XREA,
C 10, YMOHT, ZMOHT, PAMB, FMASSI, RMASS
C REAL MCIVS, HIVS, NX1, NY1, NZ1, NX2, NY2, NZ2, MTAB
C INTEGER PRINT1, PRINT2
C NAMELIST /IVSL/ XIVS, YCIVS, ZCIVS, MCIVS, PHICIV, THECIV, PTCIVS, HCIVS,
C 10, RIVS, HIVS, THETIV, PTIVS, HIVS, NPOS, PSIIV, ALPSRC, BETSRC
C NAMELIST /CNTRL/ PRINT1, PRINT2, ERROR, IVSTYP, NP, XMAX, NSTART
C NAMELIST /WALSL/ YAXIS, ZAXIS, XT, RT, RC, THETAT, XE, RE, THETA, NSYMMY,
C 10, XY1, EXPY1, XY2, EXPY2, DEDXY2, EXPY3, EXPZ1, XZ2, EXPZ2, DEDXZ2, EXPZ3, XZ1,
C 20, XY3, XZ3
C NAMELIST /AROSL/ GAMMA, RGAS, MTAB, PTAB, ATAB, ROTAB, TTAB, PAMB
C DIMENSION TITLE(12)
C
C READ INPUT DATA
C
C READ (5,350) TITLE
C READ (5,CNTRL)
C READ (5,WALSL)
C READ (5,AROSL)
C READ (5,IVSL)
C
C WRITE STANDARD COMMENTS AND TITLE
C
C WRITE (6,170)
C WRITE (6,160)

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      WRITE (6,150)
      WRITE (6,160)
      WRITE (6,180)
      WRITE (6,190)
      WRITE (6,160)
      WRITE (6,200)
      WRITE (6,160)
      WRITE (6,210) TITLE
      WRITE (6,160)
      WRITE (6,220)
C
C   STOP IF XMAX IS NOT SPECIFIED
C
C       IF (XMAX.EQ.0.0) CALL ERRORS (10)
C
C   ASSUME TABULAR THERMODYNAMIC DATA IF GAMMA IS LESS THAN ONE
C
C       IF (GAMMA.LE.1.0) GO TO 10
      WRITE (6,230) GAMMA, RGAS
      GO TO 40
C
10    WRITE (6,240)
      WRITE (6,250)
      DO 20 I=1,30
        IF (MTAB(I).EQ.0.0) GO TO 30
        NTERM=1
        IF (I.NE.16) GO TO 20
        WRITE (6,170)
        WRITE (6,160)
        WRITE (6,250)
20    WRITE (6,260) MTAB(I),PTAB(I),ATAB(I,1),ROTAB(I,1),TTAB(I,1)
30    CONTINUE
      IF (NTERM.LT.19) WRITE (6,170)
C
C   IVSTYP CANNOT EXCEED 4
C
C       IF (IVSTYP.LE.4) GO TO 50
      CALL ERRORS (1)
C
C   WRITE OUT PARAMETERS OF SPECIFIED FLOW GEOMETRY
C
50    WRITE (6,160)
      WRITE (6,270)
      IF (NPOS.EQ.0) GO TO 70
      WRITE (6,280) NPOS,XIVS,YCIVS,ZCIVS
      IF (NPOS.EQ.1) GO TO 60
      ASECT=PI/FLOAT(NPOS)
      NX2=0.0
      NY2=-SIN(ASECT)
      NZ2=COS(ASECT)
      WRITE (6,290) NX1,NY1,VZ1,NX2,NY2,NZ2
      GO TO 80
C
60    WRITE (6,360) NX1,NY1,VZ1
      GO TO 80
C

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REA 547
REA 550
REA 560
REA 570
REA 580
REA 590
REA 600
REA 610
REA 620
REA 630
REA 640
REA 650
REA 660
REA 670
REA 680
REA 690
REA 700
REA 710
REA 720
REA 730
REA 740
REA 750
REA 760
REA 770
REA 780
REA 790
REA 800
REA 810
REA 820
REA 830
REA 840
REA 850
REA 860
REA 870
REA 880
REA 890
REA 900
REA 910
REA 920
REA 930
REA 940
REA 950
REA 960
REA 970
REA 980
REA 990
REA1000
REA1010
REA1020
REA1030
REA1040
REA1050
REA1060
REA1070
REA1080
REA1090

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70	WRITE (6,370)	REAL1100
80	WRITE (6,170)	REAL1110
	WRITE (6,160)	REAL1120
	WRITE (6,300)	REAL1130
C		REAL1140
C	IF NSYMMY = 1 CONTOUR IS AXISYMETRIC	REAL1150
C		REAL1160
	IF (NSYMMY.EQ.1) GO TO 90	REAL1170
C		REAL1180
C	IF NSYMMY = 2 SUPER ELLIPTICAL WITH ALL QUADRANTS THE SAME	REAL1190
C		REAL1200
	IF (NSYMMY.EQ.2) GO TO 110	REAL1210
C		REAL1220
C	IF NSYMMY = 3 SUPER ELLIPTICAL WITH ALL QUADRANTS DIFFERENT	REAL1230
C		REAL1240
	IF (NSYMMY.EQ.3) GO TO 120	REAL1250
	CALL ERRORS (2)	REAL1260
C		REAL1270
C	TEST TO SEE IF THE NOZZLE IS CONICAL	REAL1280
C		REAL1290
90	IF (THETAT(1).EQ.THETAE(1)) GO TO 100	REAL1300
	WRITE (6,310) XT(1),YAXIS,ZAXIS,RT(1),RC(1),XE(1),RE(1),THETAT(1),	REAL1310
	THETAE(1)	REAL1320
	GO TO 140	REAL1330
C		REAL1340
100	WRITE (6,320) RT(1),RC(1),XE(1),THETAT(1)	REAL1350
	GO TO 140	REAL1360
C		REAL1370
C	SUPER ELLIPTICAL	REAL1380
C		REAL1390
C	TEST TO SEE IF EITHER INTERCEPT IS CONICAL	REAL1400
C		REAL1410
110	IF (THETAT(1).EQ.THETAE(1)) RE(1)=RT(1)+RC(1)*(1.0-COS(THETAT(1)*DRA	REAL1420
	IRAD))+(XE(1)-SIN(THETAT(1)*DRAD)*RC(1)-XT(1))*TAN(THETAT(1)*DRAD)	REAL1430
	IF (THETAT(2).EQ.THETAE(2)) RE(2)=RT(1)+RC(2)*(1.0-COS(THETAT(2)*DRA	REAL1440
	IRAD))+(XE(2)-SIN(THETAT(2)*DRAD)*RC(2)-XT(2))*TAN(THETAT(2)*DRAD)	REAL1450
	WRITE (6,330) XT(1),XT(2),YAXIS,ZAXIS,RT(1),RC(1),XE(1),RE(1),THETAT(1),	REAL1460
	THETAE(1),RT(2),RC(2),XE(2),RE(2),THETAT(2),THETAE(2)	REAL1470
	WRITE (6,340)	REAL1480
	WRITE (6,460) XY1(1),EXPY1(1),XY2(1),EXPY2(1),XY3(1),EXPY3(1),XZ1(1),	REAL1490
	EXPZ1(1),XZ2(1),EXPZ2(1),XZ3(1),EXPZ3(1),DEDXY2(1),DEDXZ2(1)	REAL1500
	GO TO 140	REAL1510
C		REAL1520
C	GENERAL SUPER ELLIPTICAL	REAL1530
C		REAL1540
120	WRITE (6,380)	REAL1550
	WRITE (6,390) YAXIS,ZAXIS	REAL1560
	WRITE (6,400)	REAL1570
C		REAL1580
C	TEST TO SEE IF ANY CONTOURS ARE CONICAL	REAL1590
C		REAL1600
	IF (THETAT(1).EQ.THETAE(1)) RE(1)=RT(1)+RC(1)*(1.0-COS(THETAT(1)*DRA	REAL1610
	IRAD))+(XE(1)-SIN(THETAT(1)*DRAD)*RC(1)-XT(1))*TAN(THETAT(1)*DRAD)	REAL1620
	WRITE (6,440) XT(1),RT(1),RC(1),XE(1),RE(1),THETAT(1),THETAE(1)	REAL1630
	WRITE (6,410)	REAL1640
	IF (THETAT(3).EQ.THETAE(3)) RE(3)=RT(1)+RC(3)*(1.0-COS(THETAT(3)*DRA	REAL1650

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1RAD))+(XE(3)-SIN(THETAT(3)*DRAD)*RC(3)-XT(3))*TAN(THETAT(3)*DRAD) REAL1660
WRITE (6,440) XT(3),RT(3),RC(3),XE(3),YE(3),THETAT(3),THETAE(3) REAL1670
WRITE (6,420) REAL1680
IF (THETAT(2).EQ.THETAE(2)) RE(2)=RT(1)+RC(2)*(1.0-COS(THETAT(2)*DRAD)) REAL1690
1RAD))+(XE(2)-SIN(THETAT(2)*DRAD)*RC(2)-XT(2))*TAN(THETAT(2)*DRAD) REAL1700
WRITE (6,440) XT(2),RT(2),RC(2),XE(2),YE(2),THETAT(2),THETAE(2) REAL1710
WRITE (6,430) REAL1720
IF (THETAT(4).EQ.THETAE(4)) RE(4)=RT(1)+RC(4)*(1.0-COS(THETAT(4)*DRAD)) REAL1730
1RAD))+(XE(4)-SIN(THETAT(4)*DRAD)*RC(4)-XT(4))*TAN(THETAT(4)*DRAD) REAL1740
WRITE (6,440) XT(4),RT(4),RC(4),XE(4),YE(4),THETAT(4),THETAE(4) REAL1750
DO 130 I=1,4 REAL1760
IF (I.EQ.4) WRITE (6,170) REAL1770
WRITE (6,450) I REAL1780
130 WRITE (6,460) XY1(I),EXPY1(I),XY2(I),EXPY2(I),XY3(I),EXPY3(I),XZ1(I),REAL1790
11),EXPZ1(I),XZ2(I),EXPZ2(I),XZ3(I),EXPZ3(I),DEDXY2(I),DEDXZ2(I) REAL1800
GO TO 140 REAL1810
C REAL1820
140 IF (INTHERM.GT.5) WRITE (6,170) REAL1830
RETURN REAL1840
C REAL1850
C REAL1860
150 FORMAT (1H0,39X,52HTHREE-DIMENSIONAL ANALYSIS OF SUPERSONIC NOZZLE REAL1870
1 FLOW) REAL1880
160 FORMAT (1H0) REAL1890
170 FORMAT (1H1) REAL1900
180 FORMAT (1H0,5X,8HABSTRACT) REAL1910
190 FORMAT (1H0,10X,118HTHIS PROGRAM WAS PRODUCED AT THE PURDUE UNIVERREAL1920
1SITY JET PROPULSION CENTER BY V. M. RANSOM AS A PART OF THE REQUIREREAL1930
2MENTS/1H ,10X,117HOF AF CONTRACT NUMBER F33615-67-C-1068. THE CONKEA1940
3TRACT WAS SPONSORED BY THE AERO PROPULSION LABORATORY WRIGHT PATTEREA1950
4RSON/1H ,10X,113HAFB, OHIO AND PRINCIPAL INVESTIGATORS FOR PURDUE KEA1960
5UNIVERSITY WERE PROFESSORS M. DOYLE THOMPSON AND JOE D. HOFFMAN./1REAL1970
6H0,10X,118HTHE EQUATIONS OF MOTION FOR A THREE-DIMENSIONAL SUPERSONEA1980
7NIC FLOW ARE SOLVED USING A NUMERICAL METHOD OF CHARACTERISTICS/1HREA1990
8 ,10X,113HHAVING SECOND-ORDER ACCURACY. THE FLOW VARIABLES MUST BEA2000
9E SPECIFIED OVER A SPACE-LIKE INITIAL VALUE SURFACE WHICH/1H ,10X,REA2010
*12HADJOINS THE NOZZLE BOUNDARIES. THE NOZZLE GEOMETRY IS SPECIFIREA2020
*ED BY MEANS OF THE SUBROUTINE WALSUB. THE NOZZLE MAY HAVE,/1H ,10REA2030
*X,112HPLANES OF SYMMETRY AND THE THERMODYNAMIC PROPERTIES OF THE GREA2040
*AS ARE DETERMINED BY MEANS OF THE SUBROUTINE AROSUB.) KEA2050
200 FORMAT (1H0,5X,17HMAJOR ASSUMPTIONS,/1H0,10X,121HTHE GASDYNAMIC MOREA2060
1DEL IS BASED ON THE FOLLOWING ASSUMPTIONS. 1. CONTINUUM, 2. INVISREA2070
2CID, 3. STEADY, 4. STRICTLY ADIABATIC,/1H ,10X,89H5. FROZEN CR EGREA2080
3UILIBRIUM CHEMICAL COMPOSITION, AND 6. SPECOTN INITIAL DATA AND BCUREA2090
4ADIABATIC.) REA2100
210 FORMAT (1H0,5X,9HJOB TITLE,/1H0,10X,12A6) REA2110
220 FORMAT (1H0,5X,19HTHERMODYNAMIC MODEL) REA2120
230 FORMAT (1H0,10X,97HACALORICALLY AND THERMALLY PERFECT GAS IS SPFCR'A2130
1IFIED AND IS CHARACTERIZED BY THE FOLLOWING VALUES,/1H0,10X,21HSPER.A2140
2CIFIC HEAT RATIO =,2X,F10.5,5X,18HAND GAS CONSTANT =,2X,F10.5,2X,18LA2150
38H(FT-LBF/LBM-DEG R)) KEA2160
240 FORMAT (1H0,10X,97HADJMENTROPIC FLOW IS ASSUMED. THE GAS PROPERTREA2170
1IES ARE INPUT AS TABULAR FUNCTIONS OF MACH NUMBER.) REA2180
250 FORMAT (1H0,12X,1HM,10X,1HP,13X,1HA,10X,3HRHO,13X,1HT,/20X,11H(LBFRFA2190
1/IN**2),4X,8H(FT/SEC),4X,11H(LBM/FT**3),5X,7H(DEG R),/) REA2200
260 FORMAT (1H ,9X,F7.3,2X,F8.3,5X,F9.2,2X,E12.4,4X,F8.1) REA2210

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270  FORMAT (1H0,5X,13HFLOW GEOMETRY)                                REA2220
280  FORMAT (1H0,10X,13HTHE FLOW HAS ,12,1X,45HPLANES OF SYMMETRY PASSING REA2230
    THROUGH THE POINT-/1H0,10X,3HX =,F10.4,1X,4H(IN),4X,3HY =,F10.4,REA2240
    2,1X,4H(IN),4X,3HZ =,F10.4,1X,4H(IN))                                REA2250
290  FORMAT (1H0,10X,64HTHE COMPONENTS OF THE OUTER NORMALS TO THE FIRST REA2260
    TWO PLANES ARE-/1H0,10X,5HXX1 =,2X,F10.6,5X,5HXY1 =,2X,F10.6,5X,REA2270
    5HYZ1 =,2X,F10.6/1H0,10X,5HXX2 =,2X,F10.6,5X,5HXY2 =,2X,F10.6,5X,REA2280
    5HYZ2 =,2X,F10.6)                                REA2290
300  FORMAT (1H0,5X,15HNOZZLE GEOMETRY)                                REA2300
310  FORMAT (1H0,10X,77HAXISYMMETRIC CIRCLE-PARABOLA CONTOURED NOZZLE HREA2310
   AVING THE FOLLOWING PARAMETERS/1H0,10X,27HTHROAT AND AXIS COORDINATE REA2320
    2TES/1H0,10X,5HXT =,F9.4,5H (IN),4X,5HYC =,F9.4,5H (IN),4X,5HZC REA2330
    3=,F9.4,5H (IN),/1H0,10X,18HCONTOUR PARAMETERS,/1H0,10X,4HRT =,F9.4,REA2340
    4,5H (IN),4X,4HRC =,F9.4,5H (IN),4X,4HXC =,F9.4,5H (IN),4X,5HRE =,REA2350
    5F9.4,/1H0,10X,8HTHETAT =,F9.4,6H (DEG),4X,8HTHETA E =,F9.4,6H (DEG) REA2360
    6)                                REA2370
320  FORMAT (1H0,10X,71HAXISYMMETRIC CIRCLE-LINE CONICAL NOZZLE HAVING REA2380
    THE FOLLOWING PARAMETERS/1H0,10X,4HRT =,F9.4,5H (IN),4X,4HRC =,F9.4,REA2390
    4,5H (IN),4X,4HXC =,F9.4,5H (IN),4X,7HALPHA =,F9.4,6H (DEG))            REA2400
330  FORMAT (1H0,10X,70HSUPERELLIPTICAL CIRCLE-PARABOLA NOZZLE HAVING REA2410
    THE FOLLOWING PARAMETERS/1H0,10X,27HTHROAT AND AXIS COORDINATES/1H0,REA2420
    2,10X,5HXTY =,F9.4,5H (IN),4X,5HXTZ =,F9.4,5H (IN),4X,5HYCT =,F9.4,REA2430
    35H (IN),4X,5HZCT =,F9.4,5H (IN)/1H0,10X,22HX-Y CONTOUR PARAMETERS/REA2440
    41H0,10X,5HRT =,F9.4,5H (IN),4X,5HRC =,F9.4,5H (IN),4X,5HXC =,F9.4,REA2450
    5,4,5H (IN),4X,5HRE =,F9.4,5H (IN)/1H0,10X,8HTHETAT =,F9.4,6H (DEG) REA2460
    6),4X,8HTHETA E =,F9.4,6H (DEG)/1H0,10X,22HX-Z CONTOUR PARAMETERS/1H0,REA2470
    70,10X,5HRT =,F9.4,5H (IN),4X,5HRC =,F9.4,5H (IN),4X,5HXC =,F9.4,REA2480
    8,5H (IN),4X,5HRE =,F9.4,5H (IN)/1H0,10X,8HTHETAT =,F9.4,6H (DEG),REA2490
    94X,8HTHETA E =,F9.4,6H (DEG))            REA2500
340  FORMAT (1H0,10X,25HSUPERELLIPTICAL EXPONENTS)                    REA2510
350  FORMAT (12A6)                                                        REA2520
360  FORMAT (1H0,10X,39HTHE COMPONENTS OF THE OUTER NORMAL ARE-/1H0,10X,REA2530
    1,5HXX1 =,2X,F10.6,5X,5HXY1 =,2X,F10.6,5X,5HYZ1 =,2X,F10.6)            REA2540
370  FORMAT (1H0,10X,21HNO PLANES OF SYMMETRY)                        REA2550
380  FORMAT (1H0,10X,67HSUPERELLIPTICAL CIRCLE-PARABOLA NOZZLE HAVING REA2560
    1( PLANES OF SYMMETRY)                                REA2570
390  FORMAT (1H0,10X,16HAXIS COORDINATES/1H0,10X,5HYCT =,F9.4,5H (IN),4X,REA2580
    1X,5HZCT =,F9.4,5H (IN))                                REA2590
400  FORMAT (1H0,10X,32HX-Y(POSITIVE) CONTOUR PARAMETERS)              REA2600
410  FORMAT (1H0,10X,32HX-Y(NEGATIVE) CONTOUR PARAMETERS)              REA2610
420  FORMAT (1H0,10X,32HX-Z(POSITIVE) CONTOUR PARAMETERS)              REA2620
430  FORMAT (1H0,10X,32HX-Z(NEGATIVE) CONTOUR PARAMETERS)              REA2630
440  FORMAT (1H0,10X,5HXT =,F9.4,5H (IN),4X,5HRT =,F9.4,5H (IN),4X,5HRE A2640
    1RC =,F9.4,5H (IN),4X,5HXC =,F9.4,5H (IN),4X,5HRE =,F9.4,5H (IN) REA2650
    2,/1H0,10X,8HTHETAT =,F9.4,6H (DEG),4X,8HTHETA E =,F9.4,6H (DEG))      REA2660
450  FORMAT (1H0,10X,36HSUPERELLIPTICAL EXPONENTS - QUADRANT,2X,11)    REA2670
460  FORMAT (1H0,10X,5HXY1 =,F9.4,5H (IN),4X,5HEY1 =,F9.4,4X,5HXY2 =,F9.4,REA2680
    1,4,5H (IN),4X,5HEY2 =,F9.4,4X,5HXY3 =,F9.4,5H (IN),4X,5HEY3 =,F9.4,REA2690
    2/1H0,10X,5HXX1 =,F9.4,5H (IN),4X,5HEZ1 =,F9.4,4X,5HXX2 =,F9.4,5H (REA2700
    3IN),4X,5HEZ2 =,F9.4,4X,5HXX3 =,F9.4,5H (IN),4X,5HEZ3 =,F9.4/1H0,10X,REA2710
    4X,8HDEUXY2 =,F9.4,9H (IN**=1),4X,8HDEUXZ2 =,F9.4,9H (IN**=1))        REA2720
    END                                                                REA2730-

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SORIGIN      8
$IDFTC WALS2
SUBROUTINE WALS2
C
C *****
C
C INITIALIZES THE SUBROUTINE WALSUB AND ASSOCIATED SUBROUTINES. THE
C PARAMETERS OF THE CIRCULAR ARC AND PARABOLIC CONTOURS ARE CALCULATED
C THESE PARAMETERS ARE DETERMINED FROM THE INPUT VALUES FOR THE
C THROAT LOCATION, RADIUS AND RADIUS OF CURVATURE, THE ANGULAR SLOPE
C AT THE TANGENT POINT BETWEEN THE CIRCLE AND PARABOLA AND THE SLOPE AT
C THE NOZZLE EXIT AND THE COORDINATES OF THE NOZZLE EXIT
C
C *****
C IN COMMON WITH DETERM
C
COMMON /COOF1/ XX(4),RR(4),AK(4),XT(4),YT(4),AN(4),BN(4),CN(4),DN(4),
14),EN(4),AAY(4),BAY(4),CAY(4),ABY(4),BBY(4),CBY(4),AAZ(4),BAZ(4),CWL
ZAZ(4),ABZ(4),BBZ(4),CBZ(4),AYTEST(4),AZTEST(4),BYTEST(4),BZTEST(4),
3,SYMMY(4)
C
C TO WALSUB
C
COMMON /TRANS/ YTRAN,ZTRAN,NTELL
C
IN COMMON WITH MAIN PROGRAM
C
COMMON /WALS2/ YO,ZO,XO(4),RT(4),RC(4),THT(4),XE(4),YE(4),THE(4),
1SYMMY,XY1(4),EY1(4),XY2(4),EY2(4),DEY2(4),EY3(4),XZ1(4),EZ1(4),XZ2
Z(4),EZ2(4),DEZ2(4),EZ3(4),XY3(4),XZ3(4)
GO TO (10,30,70), NSYMMY
C
C THE FOLLOWING IS FOR AN AXISYMMETRIC NOZZLE
C
10  GO 20 I=1,4
20  SYPMY(I)=1.0
    AK(I)=RT(I)+RC(I)
C
C INPUT FOR AN AXISYMMETRIC CASE
C
CALL CPMATE (XO(1),RT(1),RC(1),THT(1),XE(1),YE(1),THE(1),XT(1),YT
11),AN(1),BN(1),CN(1),DN(1),EN(1))
GO TO 90
C
C THE FOLLOWING IS FOR A NOZZLE SYMMETRIC ABOUT THE Y AND Z AXES.
C
30  CONTINUE
    AK(1)=RT(1)+RC(1)
    AK(2)=~T(2)+RC(2)
C
C CALL CPMATE TO DETERMINE CONTOURS
C
GO 40 I=1,2
CAL CPMATE (XO(I),RT(I),RC(I),THT(I),XE(I),YE(I),THE(I),XT(I),
1 YT(I),AN(I),BN(I),CN(I),DN(I),EN(I))

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40	CONTINUE	WLS 540
C		WLS 550
C	EQUATE PARAMETERS TO GUARANTEE SYMMETRY ABOUT THE Y AND Z AXES	WLS 560
C		WLS 570
	CO 50 I=1,2	WLS 580
	J=I+2	WLS 590
	XO(J)=XO(I)	WLS 600
	RT(J)=RT(I)	WLS 610
	RC(J)=RC(I)	WLS 620
	THT(J)=THT(I)	WLS 630
	XE(J)=XE(I)	WLS 640
	YE(J)=YE(I)	WLS 650
	THE(J)=THE(I)	WLS 660
	XT(J)=XT(I)	WLS 670
	YT(J)=YT(I)	WLS 680
	AN(J)=AN(I)	WLS 690
	BN(J)=BN(I)	WLS 700
	CN(J)=CN(I)	WLS 710
	DN(J)=DN(I)	WLS 720
	EN(J)=EN(I)	WLS 730
	AK(J)=AK(I)	WLS 740
50	CONTINUE	WLS 750
C		WLS 760
C	QUADRANT 1	WLS 770
C		WLS 780
	K=1	WLS 790
	I=1	WLS 800
	J=2	WLS 810
	CALL FESS (XO(I),RT(I),RC(I),THT(I),XE(I),YE(I),THE(I),XO(J),RT(J),	WLS 820
	I,RC(J),THT(J),XE(J),YE(J),THE(J),SYMMY(N))	WLS 830
	CALL EXPO (XY1(N),XZ1(N),XY2(N),XZ2(N),XY3(N),XZ3(N),EY1(N),EZ1(N),	WLS 840
	1,EY2(N),EZ2(N),DEY2(N),DEZ2(N),FY3(N),EZ3(N),ABY(N),BBY(N),CBY(N),	WLS 850
	2AAY(N),BAY(N),CAY(N),ABZ(N),BBZ(N),CBZ(N),AAZ(N),BAZ(N),CAZ(N),BYT	WLS 860
	3EST(N),AYTEST(N),BZTEST(N),AZTEST(N),XC(I),XC(J),XE(I),XE(J),A,SYMM	WLS 870
	4PY(N))	WLS 880
C		WLS 890
C	EQUATE THE QUADRANT PARAMETERS	WLS 900
C		WLS 910
	CO 60 N=2,4	WLS 920
	XY1(N)=XY1(I)	WLS 930
	XZ1(N)=XZ1(I)	WLS 940
	XY2(N)=XY2(I)	WLS 950
	XZ2(N)=XZ2(I)	WLS 960
	XY3(N)=XY3(I)	WLS 970
	XZ3(N)=XZ3(I)	WLS 980
	EY1(N)=EY1(I)	WLS 990
	EZ1(N)=EZ1(I)	WLS1000
	EY2(N)=EY2(I)	WLS1010
	EZ2(N)=EZ2(I)	WLS1020
	DEY2(N)=DEY2(I)	WLS1030
	DEZ2(N)=DEZ2(I)	WLS1040
	EY3(N)=EY3(I)	WLS1050
	EZ3(N)=EZ3(I)	WLS1060
	ABY(N)=ABY(I)	WLS1070
	BBY(N)=BBY(I)	WLS1080
	CBY(N)=CBY(I)	WLS1090

	AAV(N)=AAV(1)	WLS1100
	BAY(N)=BAY(1)	WLS1110
	CAY(N)=CAY(1)	WLS1120
	ABZ(N)=ABZ(1)	WLS1130
	BBZ(N)=BBZ(1)	WLS1140
	CBZ(N)=CBZ(1)	WLS1150
	AAZ(N)=AAZ(1)	WLS1160
	BAZ(N)=BAZ(1)	WLS1170
	CAZ(N)=CAZ(1)	WLS1180
	BYTEST(N)=BYTEST(1)	WLS1190
	AYTEST(N)=AYTEST(1)	WLS1200
	BZTEST(N)=BZTEST(1)	WLS1210
	AZTEST(N)=AZTEST(1)	WLS1220
	SYMMY(N)=SYMMY(1)	WLS1230
60	CONTINUE	WLS1240
	GO TO 90	WLS1250
C		WLS1260
C	NON-SYMMETRIC CONTOUR	WLS1270
C		WLS1280
70	CONTINUE	WLS1290
	DO 80 I=1,4	WLS1300
	AK(I)=RT(I)+RC(I)	WLS1310
C		WLS1320
C	GENERAL INPUT TO DETERMINE THE FOUR CONTOURS	WLS1330
C		WLS1340
C	CALL CPMATE TO SPECIFY CONTOUR CONSTANTS	WLS1350
C		WLS1360
	CALL CPMATE (XO(I),RT(I),RC(I),THT(I),XE(I),YE(I),THE(I),XT(I),	WLS1370
	YT(I),AN(I),BN(I),CN(I),DN(I),EN(I))	WLS1380
80	CONTINUE	WLS1390
C		WLS1400
C	THIS SECTION COMPUTES THE PARAMETERS NECESSARY TO SPECIFY THE	WLS1410
C	EXPONENT (AS A FUNCTION OF X) FOR EACH QUADRANT	WLS1420
C		WLS1430
C	QUADRANT 1	WLS1440
C		WLS1450
	N=1	WLS1460
	I=1	WLS1470
	J=2	WLS1480
	CALL TESS (XO(I),RT(I),RC(I),THT(I),XE(I),YE(I),THE(I),XO(J),RT(J),	WLS1490
	RC(J),THT(J),XE(J),YE(J),THE(J),SYMMY(N))	WLS1500
	CALL EXPO (XY1(N),XZ1(N),XY2(N),XZ2(N),XY3(N),XZ3(N),EY1(N),EZ1(N),	WLS1510
	EY2(N),EZ2(N),DEY2(N),DEZ2(N),EY3(N),EZ3(N),ABY(N),BBY(N),CBY(N),	WLS1520
	2AAV(N),BAY(N),CAY(N),ABZ(N),BBZ(N),CBZ(N),AAZ(N),BAZ(N),CAZ(N),BYT	WLS1530
	3EST(N),AYTEST(N),BZTEST(N),AZTEST(N),XO(I),XO(J),XE(I),XE(J),N,SYMM	WLS1540
	4PY(N))	WLS1550
C		WLS1560
C	QUADRANT 11	WLS1570
C		WLS1580
	N=2	WLS1590
	I=2	WLS1600
	J=2	WLS1610
	CALL TESS (XO(I),RT(I),RC(I),THT(I),XE(I),YE(I),THE(I),XO(J),RT(J),	WLS1620
	RC(J),THT(J),XE(J),YE(J),THE(J),SYMMY(N))	WLS1630
	CALL EXPO (XY1(N),XZ1(N),XY2(N),XZ2(N),XY3(N),XZ3(N),EY1(N),EZ1(N),	WLS1640
	EY2(N),EZ2(N),DEY2(N),DEZ2(N),EY3(N),EZ3(N),ABY(N),BBY(N),CBY(N),	WLS1650

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2AAY(N),BAY(N),CAY(N),ABZ(N),BBZ(N),CBZ(N),AAZ(N),BAZ(N),CAZ(N),BYTWLS160
3EST(N),AYTEST(N),BZTEST(N),AZTEST(N),XO(I),XO(J),XE(I),XE(J),N,SYMWLS1670
4PY(N)) WLS1680
C QUADRANT III WLS1690
C WLS1700
C WLS1710
A=3 WLS1720
I=3 WLS1730
J=4 WLS1740
CALL TESS (XO(I),RT(I),RC(I),THT(I),XE(I),YE(I),THE(I),XO(J),RT(J))WLS1750
I,RC(J),THT(J),XE(J),YE(J),THE(J),SYMMY(N)) WLS1760
CALL EXPD (XY1(N),XZ1(N),XY2(N),XZ2(N),XY3(N),XZ3(N),EY1(N),EZ1(N))WLS1770
I,EY2(N),EZ2(N),UEY2(N),DEZ2(N),EY3(N),EZ3(N),ABY(N),BBY(N),CBY(N),WLS1780
2AAY(N),BAY(N),CAY(N),ABZ(N),BBZ(N),CBZ(N),AAZ(N),BAZ(N),CAZ(N),BYTWLS1790
3EST(N),AYTEST(N),BZTEST(N),AZTEST(N),XO(I),XO(J),XE(I),XE(J),N,SYMWLS1800
4PY(N)) WLS1810
C WLS1820
C QUADRANT IV WLS1830
C WLS1840
A=6 WLS1850
I=1 WLS1860
J=4 WLS1870
CALL TESS (XO(I),RT(I),RC(I),THT(I),XE(I),YE(I),THE(I),XO(J),RT(J))WLS1880
I,RC(J),THT(J),XE(J),YE(J),THE(J),SYMMY(N)) WLS1890
CALL EXPD (XY1(N),XZ1(N),XY2(N),XZ2(N),XY3(N),XZ3(N),EY1(N),EZ1(N))WLS1900
I,EY2(N),EZ2(N),UEY2(N),DEZ2(N),EY3(N),EZ3(N),ABY(N),BBY(N),CBY(N),WLS1910
2AAY(N),BAY(N),CAY(N),ABZ(N),BBZ(N),CBZ(N),AAZ(N),BAZ(N),CAZ(N),BYTWLS1920
3EST(N),AYTEST(N),BZTEST(N),AZTEST(N),XO(I),XO(J),XE(I),XE(J),N,SYMWLS1930
4PY(N)) WLS1940
C WLS1950
C SET NSYMMY EQUAL TO TWO WLS1960
C WLS1970
NSYMMY=2 WLS1980
7TRAN=YC WLS1990
8TRAN=ZO WLS2000
NTELL=NSYMMY WLS2010
DO 100 I=1,4 WLS2020
XZ(I)=XO(I) WLS2030
RX(I)=RC(I) WLS2040
100 CONTINUE WLS2050
RETURN WLS2060
END WLS2070-

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SUBPTC TESS
  SUBROUTINE TESS (XOY,RTY,RCY,TTY,XEY,YEY,THEY,XOZ,RTZ,RCZ,TTZ,XEYES 10
  1Z-YEZ,THEZ,SOT) TES 20
C      ***** TES 30
C      ***** TES 40
C      ***** TES 50
C      TESTS TO SEE IF THE CONTOUR PARAMETERS ARE EQUAL ON ADJACENT QUAD- TES 60
C      RANTS. THE PARAMETERS ARE ALSO TESTED TO DETERMINE IF THE TES 70
C      CONTOUR IS AXISYMMETRIC. TES 80
C      ***** TES 90
C      ***** TES 100
C      IF (XOY.NE.XOZ) GO TO 10 TES 110
C      IF (RTY.NE.RTZ) GO TO 10 TES 120
C      IF (RCY.NE.RCZ) GO TO 10 TES 130
C      IF (TTY.NE.TTZ) GO TO 10 TES 140
C      IF (XEY.NE.XEZ) GO TO 10 TES 150
C      IF (YEY.NE.YEZ) GO TO 10 TES 160
C      IF (THEY.NE.THEZ) GO TO 10 TES 170
C      TES 180
C      THE QUADRANT MAY BE AXISYMMETRIC TES 190
C      TES 200
C      SOT=1. TES 210
C      GO TO 20 TES 220
C      TES 230
C      THE QUADRANT IS NOT AXISYMMETRIC TES 240
C      TES 250
C      TES 260
C      SOT=2. TES 270
C      RETURN TES 280
C      END TES 290

```

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$IBFTC EXPO
SUBROUTINE EXPO (XY1,XZ1,XY2,XZ2,XY3,XZ3,EY1,EZ1,EY2,EZ2,DEY2,DEZ2EXP 10
1,EY3,EZ3,ABY,BBY,CBY,AAZ,BAY,CAY,ABZ,BBZ,CBZ,AAZ,BAZ,CAZ,BYTES*,AYEXP 20
2TEST,BZTEST,AZTEST,XOY,XOZ,XEY,XEZ,NQ,SYMQD) EXP 30
C EXP 40
C ***** EXP 50
C EXP 60
C EVALUATES THE CONSTANTS FOR THE FUNCTION USED TO REPRESENT THE EXP 70
C X1 VARIATION OF THE EXPOENTS EXP 80
C EXP 90
C ***** EXP 100
C EXP 110
C TO DETERM EXP 120
C EXP 130
C COMMON /MIDLE/ XY2(14),XZ2J(4) EXP 140
C NSYMQD=SYMQD EXP 150
C BYTEST=2. EXP 160
C AYTEST=2. EXP 170
C BZTEST=2. EXP 180
C AZTEST=2. EXP 190
C XZ2J(NQ)=XZ2 EXP 200
C XY2(1NQ)=XY2 EXP 210
C EXP 220
C IF THE PARAMETER --TEST=1, THE CROSS-SECTION IS ELLIPTICAL. FOR EXP 230
C SYM. CASE, ITERATIONS ARE NOT NECESSARY. EXP 240
C EXP 250
C IF (EY2.EQ.2.) GO TO 40 EXP 260
C IF (EZ2.EQ.2.) GO TO 20 EXP 270
C GO TO 60 EXP 280
C EXP 290
C IF (EZ1.NE.2.) GO TO 30 EXP 300
C BZTEST=1. EXP 310
C DEZ2=0. EXP 320
C IF (EZ3.EQ.2.) AZTEST=1. EXP 330
C GO TO 60 EXP 340
C EXP 350
C IF (EY1.NE.2.) GO TO 50 EXP 360
C BYTEST=1. EXP 370
C DEY2=0. EXP 380
C IF (EY3.EQ.2.) AYTEST=1. EXP 390
C GO TO 10 EXP 400
C EXP 410
C 60 TELL=BYTEST*AYTEST*BZTEST*AZTEST*FLOAT(NSYMQD) EXP 420
C EXP 430
C IF THE --TEST VALUES ARE ALL =1., THE CROSS SECTION IS ELLIPTICAL. EXP 440
C IF IN ADDITION, NSYMQD=1 (FROM TESS) THE QUADRANT MUST BE AXISYM. EXP 450
C EXP 460
C NSYMQD=2 EXP 470
C IF (TELL.EQ.1.) NSYMQD=1 EXP 480
C EXP 490
C COEFFICIENTS FOR THE EZ FUNCTION. EXP 500
C EXP 510
C BEFORE COEFFICIENTS EXP 520
C EXP 530
C CBZ=(EZ2-EZ1+DEZ2*(XZ1-XZ2))*2.*XZ2*XZ1-XZ1**2-XZ2**2) EXP 540

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	BBZ=-2.*XZ2*CBZ+DEZ2	EXP 550
	ABZ=EZ1-BBZ*XZ1-CBZ*XZ1**2	EXP 560
C		EXP 570
C	AFTER COEFFICIENTS	EXP 580
C		EXP 590
	CAZ=(EZ2-EZ3+DEZ2*(XZ3-XZ2))/(2.*XZ2*XZ3-XZ3**2-XZ2**2)	EXP 600
	BAZ=-2.*XZ2*CAZ+DEZ2	EXP 610
	AAZ=EZ3-BAZ*XZ3-CAZ*XZ3**2	EXP 620
C		EXP 630
C	COEFFICIENTS FOR THE EY FUNCTION.	EXP 640
C		EXP 650
C	BEFORE COEFFICIENTS	EXP 660
C		EXP 670
	CBY=(EY2-EY1+DEY2*(XY1-XY2))/(2.*XY2*XY1-XY1**2-XY2**2)	EXP 680
	BBY=-2.*XY2*CBY+DEY2	EXP 690
	ABY=EY1-BBY*XY1-CBY*XY1**2	EXP 700
C		EXP 710
C	AFTER COEFFICIENTS	EXP 720
C		EXP 730
	CAY=(EY2-EY3+DEY2*(XY3-XY2))/(2.*XY2*XY3-XY3**2-XY2**2)	EXP 740
	BAY=-2.*XY2*CAY+DEY2	EXP 750
	AAZ=EY3-BAY*XY3-CAY*XY3**2	EXP 760
	RETURN	EXP 770
	END	EXP 780-

SIBFTC CPMATE		
	SUBROUTINE CPMATE (H,RT,RC,THT,XE,YE,THE,XT,YT,AN,BN,CN,DN,EN)	CPM 10
C	*****	CPM 20
C		CPM 30
C	DETERMINES THE PARAMETERS OF THE EQUATIONS FOR THE CIRCLE-PARABOLA	CPM 40
C	CONTOURS	CPM 50
C	*****	CPM 60
C		CPM 70
C		CPM 80
	DIMENSION INDEX(5), A(5,6)	CPM 90
	PI=3.1415926536	CPM 100
	THE=THE*PI/180.	CPM 110
	THT=THT*PI/180.	CPM 120
	ST=TAN(THT)	CPM 130
	SE=TAN(THE)	CPM 140
	AK=RT+RC	CPM 150
C		CPM 160
C	FIND THE POINT OF TANGENCY	CPM 170
C		CPM 180
	XT=H+ST*RC/SQRT(ST**2+1.)	CPM 190
	YT=RT+RC*(1.-COS(THT))	CPM 200
	IF (THE.EQ.THT) GO TO 10	CPM 210
C		CPM 220
C	FIND 3RD POINT ON PARABOLA	CPM 230
C		CPM 240
	XO=(YT-YE+SE*XE-ST*XT)/(SE-ST)	CPM 250
	IF (XO.LE.XT) GO TO 20	CPM 260
	IF (XO.GE.XE) GO TO 20	CPM 270
	YO=YT+ST*(XO-XT)	CPM 280
	IF (YG.GT.YE) GO TO 20	CPM 290
C		CPM 300
C	USE THE TANGENT POINT AND EXIT POINT TO FIND THE MIDDLE POINT OF	CPM 310
C	PARABOLA. TEST ON THAT POINT.	CPM 320
C		CPM 330
	XH=(XT+XE)/2.	CPM 340
	YH=(YT+YE)/2.	CPM 350
	XM=(XO+XH)/2.	CPM 360
	YM=(YO+YH)/2.	CPM 370
C		CPM 380
C	SET UP THE EQUATIONS FOR FIVE KNOWN (INCLUDING TANGENCY ANGLES),	CPM 390
C	FIVE UNKNOWN COEFFICIENTS OF GENERAL PARABOLA.	CPM 400
C		CPM 410
	A(1,1)=XE*YE	CPM 420
	A(1,2)=XE**2	CPM 430
	A(1,3)=YE	CPM 440
	A(1,4)=XE	CPM 450
	A(1,5)=1.	CPM 460
	A(1,6)=-YE**2	CPM 470
	A(2,1)=XT*YT	CPM 480
	A(2,2)=XT**2	CPM 490
	A(2,3)=YT	CPM 500
	A(2,4)=XT	CPM 510
	A(2,5)=1.	CPM 520
	A(2,6)=-YT**2	CPM 530
		CPM 540

A(3,1)=XM*YM	CPM 550
A(3,2)=XM**2	CPM 560
A(3,3)=YM	CPM 570
A(3,4)=XM	CPM 580
A(3,5)=1.	CPM 590
A(3,6)=-YM**2	CPM 600
A(4,1)=(YE+XE*SE)	CPM 610
A(4,2)=2.*XE	CPM 620
A(4,3)=SE	CPM 630
A(4,4)=1.	CPM 640
A(4,5)=0.	CPM 650
A(4,6)=-2.*YE*SE	CPM 660
A(5,1)=(YT*XT*ST)	CPM 670
A(5,2)=(2.*XT)	CPM 680
A(5,3)=ST	CPM 690
A(5,4)=1.	CPM 700
A(5,5)=0.	CPM 710
A(5,6)=-2.*YT*ST	CPM 720
CALL CROUT (A,5,1,6,C,INDEX)	CPM 730
AN=A(1,1)	CPM 740
BN=A(2,1)	CPM 750
CN=A(3,1)	CPM 760
DN=A(4,1)	CPM 770
EN=A(5,1)	CPM 780
RETURN	CPM 790
C THIS IS THE SOLUTION FOR A CONICAL CONTOUR.	CPM 800
C	CPM 810
10 YE=ST*(XE-XT)+YT	CPM 820
AN=0.	CPM 830
BN=-1.*ST**2	CPM 840
CN=0.	CPM 850
DN=2.*ST*(ST*XT-YT)	CPM 860
EN=-1.*YT**2+2.*YT*ST*XT-(XT**2)*ST**2	CPM 870
RETURN	CPM 880
20 WRITE (6,30)	CPM 890
STOP	CPM 900
C	CPM 910
C	CPM 920
30 FORMAT (1H0,10X,103H****ERROR STOP. INPUT DATA HAS RESULTED IN	CPM 930
IN IMPROPER SOLUTION FOR PARABOLIC WALL, CHECK INPUT*****;	CPM 940
END	CPM 950
	CPM 960-

SIBFTC CROUT		
SUBROUTINE CROUT (A,N,M,NN,DETERM,INDEX)		CRO 10
C		CRO 20
C	*****	CRO 30
C		CRO 40
C	STANDARD CROUT REDUCTION SUBROUTINE FOR SOLVING SYSTEMS OF LINEAR	CRO 50
C	EQUATIONS -- USED BY WALSB2 ROUTINES ONLY	CRO 60
C		CRO 70
C	*****	CRO 80
C		CRO 90
	DIMENSION A(N,NN), INDEX(N)	CRO 100
	DET=1.0	CRO 110
	JZ=N-1	CRO 120
	JA=N+1	CRO 130
	DO 10 I=1,N	CRO 140
10	INDEX(I)=I	CRO 150
	DO 180 J=1,NN	CRO 160
	DO 100 II=1,M	CRO 170
	SUM=0.0	CRO 180
	I=INDEX(II)	CRO 190
	IF (II-J) 20,60,60	CRO 200
20	IF (II-1) 30,50,30	CRO 210
30	LLLL=II-1	CRO 220
	DO 40 K=1,LLLL	CRO 230
	IPPP=INDEX(K)	CRO 240
40	SUM=SUM+A(I,K)*A(IPPP,J)	CRO 250
50	A(I,J)=(A(I,J)-SUM)/A(I,II)	CRO 260
	GO TO 100	CRO 270
C		CRO 280
60	IF (J-1) 70,90,70	CRO 290
70	LLLL=J-1	CRO 300
	DO 80 K=1,LLLL	CRO 310
	IPPP=INDEX(K)	CRO 320
80	SUM=SUM+A(I,K)*A(IPPP,J)	CRO 330
90	A(I,J)=A(I,J)-SUM	CRO 340
100	CONTINUE	CRO 350
	IF (J-N) 110,180,180	CRO 360
110	L=INDEX(J)	CRO 370
	KA=L	CRO 380
	HIGH=A(L,J)	CRO 390
	KZ=0	CRO 400
	DO 130 I=J,JZ	CRO 410
	JC=I+1	CRO 420
	L=INDEX(JC)	CRO 430
	IF (ABS(HIGH)-ABS(A(L,J))) 120,130,130	CRO 440
120	HIGH=A(L,J)	CRO 450
	KA=L	CRO 460
	KZ=1	CRO 470
130	CONTINUE	CRO 480
	IF (KZ.NE.0) DET=-DET	CRO 490
	IF (ABS(HIGH)-1.E-05) 140,140,150	CRO 500
140	WRITE (6,320) HIGH	CRO 510
150	DO 160 K=1,N	CRO 520
	KK=K	CRO 530
	IF (INDEX(K)-KA) 160,170,160	CRO 540

160	CONTINUE	CRO 550
170	ITEMP=INDEX(J)	CRO 560
	INDEX(J)=INDEX(KK)	CRO 570
	INDEX(KK)=ITEMP	CRO 580
180	CONTINUE	CRO 590
	IF (N) 190,280,190	CRO 600
190	L=N-1	CRO 610
	DO 270 J=JA,NN	CRO 620
	LL=1	CRO 630
	DO 200 K=1,N	CRO 640
	IF (ABS(A(K,J))-0.0) 240,200,240	CRO 650
200	CONTINUE	CRO 660
	IZ=INDEX(N)	CRO 670
	IF (ABS(A(IZ,N))-1.0E-02) 220,220,210	CRO 680
210	WRITE (6,330)	CRO 690
	C TO 310	CRO 700
C		CRO 710
220	A(IZ,J)=5.0000	CRO 720
	IZZ=INDEX(N-1)	CRO 730
	IF (ABS(A(IZZ,N))-1.0E-04) 230,230,240	CRO 740
230	A(IZZ,J)=2.50000	CRO 750
	LL=2	CRO 760
240	DO 260 IJ=LL,L	CRO 770
	SUM1=0.0	CRO 780
	II=N-IJ	CRO 790
	I=INDEX(II)	CRO 800
	LL=II+1	CRO 810
	DO 250 K=LL,N	CRO 820
	IP=INDEX(K)	CRO 830
250	SUM1=SUM1+A(I,K)*A(IP,J)	CRO 840
	A(I,J)=A(I,J)-SUM1	CRO 850
260	CONTINUE	CRO 860
270	CONTINUE	CRO 870
280	DETERM=1.0	CRO 880
	DO 290 I=1,N	CRO 890
	K=INDEX(I)	CRO 900
290	DETERM=DETERM*A(K,I)	CRO 910
	CETERM=DETERM*DET	CRO 920
	DO 300 I=1,N	CRO 930
	DO 300 J=JA,NN	CRO 940
	K=INDEX(I)	CRO 950
	L=J-N	CRO 960
300	A(I,L)=A(K,J)	CRO 970
310	RETURN	CRO 980
C		CRO 990
C		CRO1000
320	FORMAT (48H0THE PIVOT ELEMENT IS LESS THAN 1.E-05 VALUE IS E20.8)	CRO1010
330	FORMAT (59H0 ONLY SOLUTION IS ZERO VECTOR)	CRO1020
	END	CRO1030
		CRO1040-

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$IBFTC AROS82
SUBROUTINE AROS82
C
C
C *****
C PERFORMS INITIALIZATION CALCULATIONS FOR AROSUB -- CALCULATES GAMMA
C FUNCTIONS FOR CONSTANT GAMMA CASE AND FITS CUBIC SPLINES FOR TABULAR
C DATA INPUT FOR EQUILIBRIUM HOMETROPIC FLOW
C SUBROUTINE SPLINE IS CALLED
C
C *****
C
C REAL MTAB
COMMON /AR01/ GAMMA, RGAS, GAM1, GAM2, GAM3, GAM4, GAM5, PTAB(30), ACC(4,3)
10) , ROCO(4,30), TCO(4,30), QSCO(4,30), NFOE, NTERM, 1, 2, SJURC
COMMON /AR02/ ATAB(30,2), ROTAB(30,2), TTAB(30,2), QSTAB(30,2), PTAB(3)
10)
COMMON /CONST/ PI, DRAD, BTU, G, BTUOG
NFOE=1
C
C ASSUME TABULAR INPUT IF GAMMA IS LESS THAN ONE
C
C IF (GAMMA.LE.1.0) NFOE=2
C GO TO (10,20), NFOE
C
C CALCULATE GAMMA FUNCTIONS FOR CONSTANT GAMMA CASE
C
10 GAM3=GAMMA-1.0
   GAM2=(GAMMA+1.0)/GAM3
   GAM5=2.0/(GAMMA+1.0)
   GAM4=GAM3/2.0
   GAM1=GAM3/GAMMA
   RETURN
C
C FIT CUBIC SPLINES FOR TABULAR INPUT CASE
C
20 DO 30 I=1,NTERM
C
C CONVERT UNITS
C
C PTAB(I)=PTAB(I)*144.0
C ROTAB(NTERM,2)=(ROTAB(NTERM,1)-ROTAB(NTERM-1,1))/DELP
C ROTAB(1,1)=ROTAB(1,1)/G
C QSTAB(1,1)=(MTAB(1)*ATAB(1,1))**2
C
C TEST FOR END OF TABULAR DATA
C
C IF (I.EQ.NTERM) GO TO 40
30 IF (MTAB(I).GE.MTAB(I+1)) CALL ERRORS (14)
40 DELP=PTAB(2)-PTAB(1)
   ROTAB(1,2)=(ROTAB(2,1)-ROTAB(1,1))/DELP
   ATAB(1,2)=(ATAB(2,1)-ATAB(1,1))/DELP
   QSTAB(1,2)=(QSTAB(2,1)-QSTAB(1,1))/DELP
   TTAB(1,2)=(TTAB(2,1)-TTAB(1,1))/DELP
   DELP=PTAB(NTERM)-PTAB(NTERM-1)

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ATAB(NTHERM,2)=(ATAB(NTHERM,1)-ATAB(NTHERM-1,1))/DELP	ARS 550
QSTAB(NTHERM,2)=(QSTAB(NTHERM,1)-QSTAB(NTHERM-1,1))/DELP	ARS 560
TTAB(NTHERM,2)=(TTAB(NTHERM,1)-TTAB(NTHERM-1,1))/DELP	ARS 570
CALL SPLINE (NTHERM,PTAB,ATAB,ACO)	ARS 580
CALL SPLINE (NTHERM,PTAB,ROTAB,ROCO)	ARS 590
CALL SPLINE (NTHERM,PTAB,QSTAB,QSCO)	ARS 600
CALL SPLINE (NTHERM,PTAB,TTAB,TCO)	ARS 610
I=2	ARS 620
RETURN	ARS 630
END	ARS 640-

```

3ORIGIN      B
3IBFTC IVSURF
      SUBROUTINE 'VSURF
C
C *****
C
C THE INITIAL VALUE SURFACE NETWORK OF POINTS IS CONSTRUCTED AND THE
C COORDINATES ARE STORED IN THE Y AND Z ARRAYS OF COMMON /SOLUTN/
C WRITTEN BY R. CRAIGIN FEB. 1969
C
C *****
C
C DIMENSION Y1(183,2), Z1(183,2), R1(183,2), S1(183,2), RATIO(29)
C COMMON /SOLUTN/ Y(2,19,19),Z(2,19,19),U(2,19,19),V(2,19,19),W(2,19,19),
C P(2,19,19),PT(19,19),H(19,19),KLASS(19,19)
C COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,JJ,LL,
C ISTART,DELX,ODELX,KK,X(2),XMAX,NO
C COMMON /CONST/ PI,DRAD,BTU,G,BTUOG
C COMMON /IVS/ XSDRC,YSDRC,ZSDRC,XIVS,YCIVS,ZCIVS,MCIVS,PHICIV,THETIVS
C IV,PTCIVS,MCIVS,RIVS,MIVS,THETIV,PSIV,PPIVS,HIVS,XPSORC,YPSORC,ZPSIVS
C ZCRC,ALPSRC,BETSRC
C COMMON /PLANES/ NPOS,NR1,NY1,NZ1,NX2,NY2,NZ2
C DIMENSION RIVS(30), MIVS(30), THETIV(30), PTIVS(30,2), HIVS(30,2),
C PSIV(30)
C REAL MCIVS,HIVS,NX1,NY1,NZ1,NX2,NY2,NZ2
C INTEGER PRINT1,PRINT2
C XU=XIVS
C YC=YCIVS
C ZC=ZCIVS
C NP3=NP-1
C DIRX=0.0
C
C LOGIC FOR PLANES OF SYMMETRY
C
C IF (NPOS.GE.3) GO TO 40
C ICLASS=4-NPOS
C NPOS1=NPOS+1
C GO TO (10,20,30), NPOS1
C
C NO PLANES OF SYMMETRY -- AN NT BY NT NETWORK IS CONSTRUCTED
C
C 10 ASECT=2.0*PI
C NP1=180
C KM=1
C KN=2
C KI=8
C NO=2*NP-1
C GO TO 50
C
C 1 PLANE OF SYMMETRY -- AN NT BY NP NETWORK IS CONSTRUCTED
C
C 20 ASECT=PI
C NP1=180
C KM=1
C KN=2

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```

IVS 10
IVS 20
IVS 30
IVS 40
IVS 50
IVS 60
IVS 70
IVS 80
IVS 90
IVS 100
IVS 110
IVS 120
IVS 130
IVS 140
IVS 150
IVS 160
IVS 170
IVS 180
IVS 190
IVS 200
IVS 210
IVS 220
IVS 230
IVS 240
IVS 250
IVS 260
IVS 270
IVS 280
IVS 290
IVS 300
IVS 310
IVS 320
IVS 330
IVS 340
IVS 350
IVS 360
IVS 370
IVS 380
IVS 390
IVS 400
IVS 410
IVS 420
IVS 430
IVS 440
IVS 450
IVS 460
IVS 470
IVS 480
IVS 490
IVS 500
IVS 510
IVS 520
IVS 530

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	K1=4	IVS 540
	NO=2*NP-1	IVS 550
	GO TO 50	IVS 560
C		IVS 570
C	2 PLANES OF SYMMETRY -- AN NP BY NP NETWORK IS CONSTRUCTED	IVS 580
C		IVS 590
30	ASECT=PI/2.0	IVS 600
	NP1=90	IVS 610
	KH=1	IVS 620
	KH=1	IVS 630
	K1=2	IVS 640
	NO=NP	IVS 650
	GO TO 50	IVS 660
C		IVS 670
C	3 OR MORE PLANES OF SYMMETRY -- AN NP BY NP TRIANGULAR ARRAY IS	IVS 680
C	CONSTRUCTED	IVS 690
C		IVS 700
40	ICLASS=1	IVS 710
	ASECT=PI/FLOAT(NP05)	IVS 720
	NP1=60	IVS 730
	KH=0	IVS 740
	KH=1	IVS 750
	K1=1	IVS 760
	NO=NP	IVS 770
C		IVS 780
C	1 ESTIMATED BOUNDARY POINTS LIE ON AN INSCRIBED CIRCLE OF RADIUS R	IVS 790
C		IVS 800
50	R=0.1	IVS 810
	S1(1,1)=0.0	IVS 820
	K=1	IVS 830
C		IVS 840
C	A TABLE OF BOUNDARY POINTS IS CONSTRUCTED USING WALSUB IN ORDER	IVS 850
C	TO DEFINE THE CONTOUR PERIMETER AT THE INITIAL VALUE SURFACE	IVS 860
C		IVS 870
	NP11=NP1+1	IVS 880
	NP22=NP1+2	IVS 890
	DO 70 I=1, NP11	IVS 900
	T=ASECT*FLOAT(I-1)/FLOAT(NP1)	IVS 910
	DIRZ=SIN(T)	IVS 920
	DIRY=COS(T)	IVS 930
	Y1(I,K)=R*DIRY+Y0	IVS 940
	Z1(I,K)=R*DIRZ+Z0	IVS 950
	CALL WALSUB (X0,Y1(I,K),Z1(I,K),DIRX,DIRY,DIRZ)	IVS 960
	K1(I,K)=SQRT((Y1(I,K)-Y0)**2+(Z1(I,K)-Z0)**2)	IVS 970
	IF (I-2) 70,60,60	IVS 980
C		IVS 990
C	APPROXIMATE THE PERIMETER BY A SERIES OF CHORDS	IVS1000
C		IVS1010
60	S1(I,K)=SQRT((Y1(I,K)-Y1(I-1,K))**2+(Z1(I,K)-Z1(I-1,K))**2)+S1(I	IVS1020
	I-1,K)	IVS1030
70	CONTINUE	IVS1040
	CO 180 N=1, NP3	IVS1050
	IF (N.EQ.1) GO TO 100	IVS1060
	K=2	IVS1070
	S1(I,K)=0.0	IVS1080
C		IVS1090

```

C 1 DIVIDE RADIUS INTO INCREMENTS FOR INNER LEVELS IVS1100
C IVS1110
RATIO(N)=COS(FLOAT(KM)*PI/4.+FLOAT(1-KM)*(PI/2.-ASECT))+(FLCAT(KI)VS1120
1 M)*PI/4.+FLOAT(1-KM)*ASECT)*(FLOAT(N-1)/FLOAT((NO-1)/KN))/COS(IVS1130
2 FLOAT(KM)*PI/4.+FLOAT(1-KM)*(PI/2.-ASECT)) IVS1140
C IVS1150
C NP1 INTERIOR POINTS ARE CONSTRUCTED FROM THE NP1 BOUNDARY POINTS IVS1160
C IVS1170
DO 90 I=1,NP1 IVS1180
T=ASECT*FLOAT(I-1)/FLOAT(NP1) IVS1190
R1(I,K)=RATIO(H)*R1(I,1) IVS1200
Y1(I,K)=R1(I,K)*COS(T)+Y0 IVS1210
Z1(I,K)=R1(I,K)*SIN(T)+Z0 IVS1220
IF (I-2) 90,80,80 IVS1230
C IVS1240
C FIND PERIMETER OF INNER LEVELS IVS1250
C IVS1260
80 S1(I,K)=SQRT((Y1(I,K)-Y1(I-1,K))**2+(Z1(I,K)-Z1(I-1,K))**2)+IVS1270
1 S1(I-1,K) IVS1280
90 CONTINUE IVS1290
100 DELS2=S1(NP1,K)/FLOAT(KI*(NP-N)) IVS1300
S2=0.0 IVS1310
C IVS1320
C THE COORDINATES OF POINTS LOCATED AT EQUAL INTERVALS OF ARC LENGTH IVS1330
C ALONG THE BOUNDARY OR ALONG INTERIOR CURVES GEOMETRICALLY SIMILAR IVS1340
C TO THE BOUNDARY ARE FOUND IVS1350
C IVS1360
M=0 IVS1370
NPP=NP-N IVS1380
NPM1=NP1 IVS1390
IF (NPOS.EQ.0) NPM1=NP1 IVS1400
C IVS1410
C LOGIC TO DETERMINE INDICIAL COORDINATES OF POINTS IVS1420
C IVS1430
DO 170 I=1,NPM1 IVS1440
IF (M.LE.NPP) GO TO 110 IVS1450
IF (M.LE.3*NPP) GO TO 120 IVS1460
IF (M.LE.5*NPP) GO TO 130 IVS1470
IF (M.LE.7*NPP) GO TO 140 IVS1480
NI=N IVS1490
NJ=NP-M+8*NPP IVS1500
GO TO 150 IVS1510
C IVS1520
110 NI=N IVS1530
NJ=NP-N IVS1540
GO TO 150 IVS1550
C IVS1560
120 NI=M+2*N-NP IVS1570
NJ=M IVS1580
GO TO 150 IVS1590
C IVS1600
130 NI=2*NPP+N IVS1610
NJ=M+N-3*NPP IVS1620
GO TO 150 IVS1630
C IVS1640
140 NI=N-M+7*NPP IVS1650

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	NJ=M+2*NPP	IVS1560
150	CONTINUE	IVS1670
	IF (I.EQ.1) GO TO 170	IVS1680
	IF (S2-S1(I,K)) 160,160,170	IVS1690
C		IVS1700
C	CALCULATE Y,Z COORDINATES OF POINTS	IVS1710
C		IVS1720
160	Y(1,NI,NJ)=(Y1(I,K)-Y1(I-1,K))*((S2-S1(I-1,K))/(S1(I,K)-S1(I-1,K)))+Y1(I-1,K)	IVS1730
	Z(1,NI,NJ)=(Z1(I,K)-Z1(I-1,K))*((S2-S1(I-1,K))/(S1(I,K)-S1(I-1,K)))+Z1(I-1,K)	IVS1740
		IVS1750
C		IVS1760
C	CALCULATE INITIAL DATA AT THE POINT	IVS1770
C		IVS1780
	CALL INVALS (NI,NJ)	IVS1790
	S2=S2+DELS2	IVS1800
	M=M+1	IVS1810
170	CONTINUE	IVS1820
180	CONTINUE	IVS1830
C		IVS1840
C	COORDINATES AND INITIAL DATA AT CENTRAL POINT	IVS1850
C		IVS1860
	Y(1,NP,NP)=Y0	IVS1870
	Z(1,NP,NP)=Z0	IVS1880
	CALL INVALS (NP,NP)	IVS1890
C		IVS1900
C	RETURN IF NO PLANES OF SYMMETRY	IVS1910
C		IVS1920
	IF (ICLASS.EQ.4) RETURN	IVS1930
C		IVS1940
C	REFLECT POINTS WITH RESPECT TO PLANES OF SYMMETRY	IVS1950
C		IVS1960
	CALL REFLECT (L)	IVS1970
	GO TO (190,210,240), ICLASS	IVS1980
C		IVS1990
C	REFLECT PROPERTIES PT AND H FOR PLANES OF SYMMETRY	IVS2000
C		IVS2010
190	NP1=NP-1	IVS2020
	DO 200 I=1,NP	IVS2030
	PT(I,NP+1)=PT(I,NP1)	IVS2040
	H(I,NP+1)=H(I,NP1)	IVS2050
	PT(I+1,I)=PT(I,I+1)	IVS2060
200	H(I+1,I)=H(I,I+1)	IVS2070
	PT(NP+1,NP1)=PT(NP1,NP+1)	IVS2080
	H(NP+1,NP1)=H(NP1,NP+1)	IVS2090
	PT(NP+1,NP+1)=PT(NP+1,NP1)	IVS2100
	H(NP+1,NP+1)=H(NP+1,NP1)	IVS2110
	PT(1,NP+2)=PT(1,NP-2)	IVS2120
	H(1,NP+2)=H(1,NP-2)	IVS2130
	PT(3,1)=PT(1,3)	IVS2140
	H(3,1)=H(1,3)	IVS2150
	RETURN	IVS2160
C		IVS2170
C	2 PLANES OF SYMMETRY	IVS2180
C		IVS2190
		IVS2200
210	NP2=NP+2	IVS2210

CO 220 I=1,NP	
PT(I,NP+1)=PT(I,NP-1)	IVS2220
H(I,NP+1)=H(I,NP-1)	IVS2230
PT(I,NP+2)=PT(I,NP-2)	IVS2240
220 H(I,NP+2)=H(I,NP-2)	IVS2250
CO 230 I=1,NP2	IVS2260
PT(NP+1,I)=PT(NP-1,I)	IVS2270
H(NP+1,I)=H(NP-1,I)	IVS2280
PT(NP+2,I)=PT(NP-2,I)	IVS2290
230 H(NP+2,I)=H(NP-2,I)	IVS2300
RETURN	IVS2310
C	IVS2320
C 1 PLANE OF SYMMETRY	IVS2330
C	IVS2340
240 NP2=NP+2	IVS2350
CO 250 I=1,NT	IVS2360
PT(I,NP+1)=PT(I,NP-1)	IVS2370
H(I,NP+1)=H(I,NP-1)	IVS2380
PT(I,NP2)=PT(I,NP-2)	IVS2390
250 H(I,NP2)=H(I,NP-2)	IVS2400
RETURN	IVS2410
END	IVS2420
	IVS2430-



C	THRUST DATA AND BOUNDARY POINTS	PRI 540
C		PRI 550
40	WRITE (6,100) XIVS	PRI 560
	WRITE (6,140) AREAT, FMASS, XTHR, YTHR, ZTHR, XMOMT, YMOMT, ZMOMT	PRI 570
	WRITE (6,160)	PRI 580
	WRITE (6,110)	PRI 590
	WRITE (6,120)	PRI 600
	J2=NP	PRI 610
	IF (ICLASS.EQ.4) J2=NO	PRI 620
	DO 70 I=1,NO,PRINT2	PRI 630
	J1=1	PRI 640
	IF (ICLASS.EQ.1) J1=1	PRI 650
	DO 70 J=J1,J2,PRINT2	PRI 660
	IF (I.EQ.1.OR.J.EQ.1) GO TO 50	PRI 670
	IF (I.EQ.NO.OR.J.EQ.NO) GO TO 50	PRI 680
	GO TO 70	PRI 690
C		PRI 700
50	IF (LINE.LE.54) GO TO 60	PRI 710
	WRITE (6,100) XIVS	PRI 720
	WRITE (6,110)	PRI 730
	WRITE (6,120)	PRI 740
	LINE=1	PRI 750
60	TOLP=PT(1,J)/144.0	PRI 760
	LINE=LINE+1	PRI 770
	TOLH=H(1,J)/8TUOG	PRI 780
	WRITE (6,130) I,J,Y(1,1,J),Z(1,1,J),W(2,1,J),Z(2,1,J),Y(2,1,J),	PRI 790
	V(2,1,J),P(2,1,J),U(1,1,J),V(1,1,J),W(1,1,J),TOLP,TOLH	PRI 800
70	CONTINUE	PRI 810
	GO TO 90	PRI 820
C		PRI 830
C	THRUST DATA ONLY	PRI 840
C		PRI 850
80	WRITE (6,100) XIVS	PRI 860
	WRITE (6,140) AREAT, FMASS, XTHR, YTHR, ZTHR, XMOMT, YMOMT, ZMOMT	PRI 870
90	WRITE (6,170) MMM,NNN,SAFTY,DELX	PRI 880
	RETURN	PRI 890
C		PRI 900
C		PRI 910
100	FORMAT (1H,5X,14HINITIAL DATA -,10X,3HX =,2X,F8.4,1X,4H(IN))	PRI 920
110	FORMAT (1H0,10X,1H,2X,1HJ,6X,1HY,8X,1HZ,8X,1HM,8X,1HQ,9X,1HP,7X,3P	PRI 930
	1HRHO,9X,1HT,9X,1HU,10X,1HV,8X,1HW,7X,2HPT,8X,1HH)	PRI 940
120	FORMAT (1H,18X,4H(IN),5X,4H(IN),12X,8H(FT/SEC),1X,9H(LBF/IN2),2X,P	PRI 950
	19H(16M/FT3),2X,7H(DEG R),3X,8H(FT/SEC),2X,8H(FT/SEC),1X,8H(FT/SEC)	PRI 960
	2,9H(LBF/IN2),1X,9H(BTU/LBM)/)	PRI 970
130	FORMAT (1H,9X,12,1X,12,2X,F7.4,2X,F7.4,2X,F7.3,2X,F7.1,2X,F8.2,2X	PRI 980
	1,E10.4,2X,F7.1,2X,F8.1,2X,F8.1,2X,F7.1,2X,F7.1,2X,F8.1)	PRI 990
140	FORMAT (1H0,10X,17HTHRUST PARAMETERS//1H,10X,20HCROSS SECTION ARE	PRI 1000
	1A =,2X,F10.4,2X,7H(IN**2),4X,11HMASS FLOW =,2X,F10.4,2X,9H(LBM/SEC	PRI 1010
	2),/1H,10X,9HXTHRUST =,2X,F9.2,1X,5H(LBF),6X,9HYTHRUST =,2X,F7.2	PRI 1020
	31X,5H(LBF),6X,9HZTHRUST =,2X,F7.2,1X,5H(LBF),/1H,10X,9HXMOMT	PRI 1030
	4,2X,F9.2,1X,8H(FT-LBF),3X,9HYMOMT =,2X,F7.2,1X,8H(FT-LBF),3X,9HZ	PRI 1040
	5MOMT =,2X,F7.2,1X,8H(FT-LBF))	PRI 1050
150	FORMAT (1H0,10X,37HBOUNDARY AND INTERIOR FLOW PARAMETERS)	PRI 1060
160	FORMAT (1H0,10X,24HBOUNDARY FLOW PARAMETERS)	PRI 1070
170	FORMAT (1H0,10X,27HSTEP REGULATION PARAMETERS//1H,10X,19HLIMITIN	PRI 1080
	16 POINT I =,1X,12,5H AND,1X,3HJ =,1X,12,5X,16HSAFETY FACTOR =,F	PRI 1090
	210.5,5X,10HDELTA X =,F10.4)	PRI 1100
	END	PRI 1110-

\$IBFTC INTXRG		IRG 10
SUBROUTINE INTXRG		IRG 20
C *****		IRG 30
C		IRG 40
C ESTABLISHES INITIAL XSTEP TO BE USED BY SEARCHING INITIAL VALUE		IRG 50
C SURFACE FOR THE MOST RESTRICTIVE POINT		IRG 60
C *****		IRG 70
C *****		IRG 80
C		IRG 90
COMMON /SOLUTH/ Y(2,19,19),Z(2,19,19),L(2,19,19),V(2,19,19),W(2,19,19),P(2,19,19),PT(19,19),H(19,19),KCLASS(19,19)		IRG 100
COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,JJ,L,LL,IRG 110		IRG 120
INSTART,DELX,ODELX,KK,X(2),XMAX,NO		IRG 130
COMMON /XRGLT/ RM(2,19,19),DXDL(2,19,19),EXCNTR,DELMN,PPM,NNN,SAFIRG 140		IRG 150
ITY		IRG 160
INTEGER PRINT1,PRINT2		IRG 170
C		IRG 180
C LOGIC FOR DIFFERENT NUMBERS OF PLANES OF SYMMETRY		IRG 190
C		IRG 200
GO TO (10,20,30,40), ICLASS		IRG 210
10 CONTINUE		IRG 220
20 II=NP		IRG 230
JJ=NP		IRG 240
GO TO 50		IRG 250
C		IRG 260
30 II=NT		IRG 270
JJ=NP		IRG 280
GO TO 50		IRG 290
C		IRG 300
40 II=NT		IRG 310
JJ=NT		IRG 320
50 CONTINUE		IRG 330
DO 150 I=1,II		IRG 340
J1=1		IRG 350
IF (ICLASS.EQ.1) J1=1		IRG 360
DO 150 J=J1,JJ		IRG 370
C		IRG 380
C CALCULATE STEP SIZE RATIO AT POINT FROM MACH NO. STORED IN W(2,I,J)		IRG 390
C AND Q STORED IN Z(2,I,J)		IRG 400
C		IRG 410
DXDL(1,I,J)=U(1,I,J)**2/Z(2,I,J)**2*(SQRT(W(2,I,J)**2-1.0)-SQRT		IRG 420
1 (ABS(Z(2,I,J)**2/U(1,I,J)**2-1.0)))		IRG 430
C		IRG 440
C LOGIC FOR SELECTING NEIGHBORING POINTS		IRG 450
C		IRG 460
RSM=0.0		IRG 470
MM1=I-1		IRG 480
MM2=I+1		IRG 490
NN1=J-1		IRG 500
NN2=J+1		IRG 510
IF (I.GT.1) GO TO 60		IRG 520
MM1=1		IRG 530
MM2=3		IRG 540
60 IF (I.LT.NT) GO TO 70		

	MM1=11-2	IRG 550
	MM2=11	IRG 560
70	IF (J.GT.1) GO TO 80	IRG 570
	NN1=J	IRG 580
	NN2=3	IRG 590
80	IF (J.LT.NT) GO TO 90	IRG 600
	NN1=JJ-2	IRG 610
	NN2=JJ	IRG 620
C		IRG 630
C	SEARCH FOR MINIMUM DISTANCE TO NEIGHBORING POINT	IRG 640
C		IRG 650
90	DO 110 K=MM1,MM2	IRG 660
	DO 110 N=NN1,NN2	IRG 670
	IF (K.EQ.1.AND.N.EQ.J) GO TO 110	IRG 680
	RS=(Y(1,K,N)-Y(1,1,J))**2+(Z(1,K,N)-Z(1,1,J))**2	IRG 690
	IF (RSM.EQ.0.0) GO TO 100	IRG 700
	IF (RS.GT.RSM) GO TO 110	IRG 710
100	RSM=RS	IRG 720
110	CONTINUE	IRG 730
	RM(1,1,J)=SQRT(RSM)	IRG 740
	RM(2,1,J)=RM(1,1,J)	IRG 750
C		IRG 760
C	CALCULATE THE ESTIMATED XSTEP AT THE POINT	IRG 770
C		IRG 780
	DX=RM(1,1,J)*DXDL(1,1,J)	IRG 790
C		IRG 800
C	SEARCH FOR THE SMALLEST XSTEP	IRG 810
C		IRG 820
	IF (DELX.GT.0.0) GO TO 120	IRG 830
	DELXMN=DX	IRG 840
	DELX=DX	IRG 850
	MMM=I	IRG 860
	NNN=J	IRG 870
	GO TO 140	IRG 880
C		IRG 890
120	IF (DX.LT.DELX) GO TO 130	IRG 900
	GO TO 140	IRG 910
C		IRG 920
130	DELX=DX	IRG 930
	DELXMN=DX	IRG 940
	MMM=I	IRG 950
	NNN=J	IRG 960
140	CONTINUE	IRG 970
150	CONTINUE	IRG 980
	COELX=DELX	IRG 990
C		IRG1000
C	MULTIPLY ESTIMATED XSTEP BY THE SAFTY FACTOR	IRG1010
C		IRG1020
C		IRG1030
	CELX=DELX*0.64	IRG1040
	RETURN	IRG1050-
	END	

```

$IBFTC LABAL
SUBROUTINE LABAL
C
C *****
C
C ASSIGN LABELS IN ARRAY KCLASS TO EACH POINT. THESE LABELS ARE USED
C BY INTERP TO DETERMINE WHICH POINTS TO USE FOR FITTING LEAST SQUARE
C POLYNOMIALS. THE LABEL CONSISTS OF TWO DIGITS, THE FIRST GIVING
C THE NUMBER FOR THE ONE-EIGHTH SECTOR OF THE GRID IN WHICH THE POINT
C IS LOCATED (1-8) AND THE SECOND INDICATES THE TYPE OF STENCIL TO USE
C IN INTERP (1-9).
C
C *****
C
COMMON /SOLUTN/ Y(2,19,19),Z(2,19,19),U(2,19,19),V(2,19,19),W(2,19,19),
1,19),P(2,19,19),PT(19,19),H(19,19),KCLASS(19,19)
COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,JJ,L,LL,
INSTART,DELX,ODELX,KK,X(2),XMAX,NO
INTEGER PRINT1,PRINT2
M1=NP
N1=NT
C
C LABEL THE FIRST ONE-EIGHTH SECTOR OF THE GRID
C
KCLASS(1,1)=21
KCLASS(2,2)=16
KCLASS(1,2)=12
DO 50 J=3,M1
DO 50 I=1,J
JJJ=(M1-1)/2+(I+1)/2
IF (I.EQ.1.AND.J.LT.JJJ) GO TO 10
IF (I.EQ.1) GO TO 40
IF (I.EQ.J) GO TO 20
IF (J.LE.JJJ) GO TO 30
KCLASS(I,J)=19
GO TO 50
C
10 KCLASS(I,J)=13
GO TO 50
C
20 KCLASS(I,J)=16
GO TO 50
C
30 KCLASS(I,J)=15
GO TO 50
C
40 KCLASS(I,J)=14
50 CONTINUE
KCLASS(M1-1,M1-1)=17
C
C LABEL THE REMAINING ONE-EIGHT SECTORS OF GRID BY REFLECTION
C
IF (ICLASS.EQ.1) GO TO 120
DO 60 J=2,M1
J1=J-1

```

CU 60 I=1,J1	LAB 550
KLASS(J,I)=KLASS(I,J)+10	LAB 560
IF (ICLASS.EQ.2) GO TO 60	LAB 570
II1=II+1-I	LAB 580
II2=II+1-J	LAB 590
KLASS(II2,I)=KLASS(I,J)+20	LAB 600
KLASS(II1,J)=KLASS(I,J)+30	LAB 610
IF (ICLASS.EQ.3) GO TO 60	LAB 620
KLASS(II1,II2)=KLASS(I,J)+40	LAB 630
KLASS(II2,II1)=KLASS(I,J)+50	LAB 640
KLASS(J,II1)=KLASS(I,J)+60	LAB 650
KLASS(I,II2)=KLASS(I,J)+70	LAB 660
60 CONTINUE	LAB 670
C	LAB 680
C LABEL THE DIAGONAL ELEMENTS	LAB 690
C	LAB 700
PM1=M1-1	LAB 710
CO 80 I=2,PM1	LAB 720
IF (ICLASS.EQ.2) GO TO 80	LAB 730
II1=II+1-I	LAB 740
IF (ICLASS.EQ.3) GO TO 70	LAB 750
KLASS(I,II1)=KLASS(I,I)+60	LAB 760
KLASS(II1,II1)=KLASS(I,I)+40	LAB 770
70 KLASS(II1,I)=KLASS(I,I)+20	LAB 780
80 KLASS(I,I)=KLASS(I,I)+10	LAB 790
C	LAB 800
C CORRECT THE LABELING FOR SPECIAL CASES	LAB 810
C	LAB 820
IF (ICLASS.LT.4) GO TO 100	LAB 830
NN=M1-1	LAB 840
CU 90 I=1,NN	LAB 850
C	LAB 860
C CORRECT LAST COLUMN OF SECTOR 8 TO SECTOR 1	LAB 870
C	LAB 880
90 KLASS(I,M1)=KLASS(I,M1)-70	LAB 890
100 IF (ICLASS.EQ.2) GO TO 110	LAB 900
C	LAB 910
C LABEL CORNER POINTS	LAB 920
C	LAB 930
KLASS(1,11)=81	LAB 940
KLASS(11,11)=61	LAB 950
KLASS(11,1)=41	LAB 960
C	LAB 970
C CENTER POINT STENCIL FOR 0, 1, OR 2 PLANES OF SYMMETRY	LAB 980
C	LAB 990
110 KLASS(M1,M1)=18	LAB1000
RETURN	LAB1010
C	LAB1020
C CENTER POINT STENCIL FOR 3 OR MORE PLANES OF SYMMETRY	LAB1030
C	LAB1040
120 KLASS(M1,M1)=19	LAB1050
RETURN	LAB1060
END	LAB1070-

```

$ORIGIN      A
$IBF'C BRAIN
SUBROUTINE BRAIN
C
C *****
C
C CONTROLS INTEGRATION BETWEEN SUCCESSIVE SOLUTION SURFACES
C
C *****
C
COMMON /SOLUTN/ Y(2,19,19),Z(2,19,19),L(2,19,19),V(2,19,19),W(2,19,19),
1,19),P(2,19,19),PT(19,19),H(19,19),KCLASS(19,19)
COMMON /XRGLT/ RM(2,19,19),DXDL(2,19,19),EXCNTR,DELMXN,PMN,NAN,SF
1TY
COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,LL,LL,
INSTART,DELX,ODELX,KK,X(2),XMAX,NO
COMMON /THRUT/ AREA:AREAT,FMASS,XTHRI,YTHRI,ZTHRI,XTHR,YTHR,ZTHR,XDRA
1MONT,YMONT,ZMONT,PAMB,FMASSI,RMASS
INTEGER PRNT1,PRNT2
C
C IF NSTART IS .LT. ZERO, NO TAPE IS REQUIRED
C IF NSTART IS .EQ. ZERO, A NORMAL START IS MADE WITH THE SOLUTION
C   STORED ON TAPE
C IF NSTART IS .GT. ZERO, START FROM TAPE
C
C   IF (INSTART.GT.0) GO TO 60
C
C SET INDICES FOR PLANES OF SYMMETRY CASES
C
C   GO TO (10,20,30,40), ICLASS
10 CONTINUE
20   I11=NP+2
   JJ1=NP+2
   GO TO 50
C
30   I11=NT
   JJ1=NP+2
   GO TO 50
C
40   I11=NT
   JJ1=NT
50 CONTINUE
   IF (INSTART.LT.0) GO TO 140
   ASTART=0
C
C NEW START
C
C   REWIND 7
C
C WRITE TYPE AND SIZE OF ARRAYS ON TAPE
C
C   WRITE (7) ICLASS,NP,NT,FMASSI
C   GO TO 140
C
C START FROM TAPE

```

```

BRA 10
BRA 20
BRA 30
BRA 40
BRA 50
BRA 60
BRA 70
BRA 80
BRA 90
BRA 100
BRA 110
BRA 120
BRA 130
BRA 140
BRA 150
BRA 160
BRA 170
BRA 180
BRA 190
BRA 200
BRA 210
BRA 220
BRA 230
BRA 240
BRA 250
BRA 260
BRA 270
BRA 280
BRA 290
BRA 300
BRA 310
BRA 320
BRA 330
BRA 340
BRA 350
BRA 360
BRA 370
BRA 380
BRA 390
BRA 400
BRA 410
BRA 420
BRA 430
BRA 440
BRA 450
BRA 460
BRA 470
BRA 480
BRA 490
BRA 500
BRA 510
BRA 520
BRA 530

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C		BRA 540
60	REWIND 7	BRA 550
C		BRA 560
C	READ TYPE AND SIZE OF ARRAYS FROM TAPE	BRA 570
C		BRA 580
	READ (7) ICLAS,NP1,NT1,FMASSI	BRA 590
	IF (ICLAS.NE.ICLASS) CALL ERRORS (15)	BRA 600
	IF (NP1.NE.NP) CALL ERRORS (15)	BRA 610
	IF (NT1.NE.NT) CALL ERRORS (15)	BRA 620
	GO TO (70,80,90,100), ICLASS	BRA 630
70	CONTINUE	BRA 640
80	I11=NP+2	BRA 650
	JJ1=NP+2	BRA 660
	GO TO 110	BRA 670
90	I11=NT	BRA 690
	JJ1=NP+2	BRA 700
	GO TO 110	BRA 710
C		BRA 720
100	I11=NT	BRA 730
	JJ1=NT	BRA 740
110	CONTINUE	BRA 750
C		BRA 760
C	START TAPE SEARCH	BRA 770
C		BRA 780
	WRITE (6,220) NSTART	BRA 790
	GO 120 N=1,100	BRA 800
	READ (7) XK-X(2),MM,NVN,SAFTY,DELXMM,DELX,RPASS,((Y(2,I,J),Z(2,I,J),U(2,I,J),V(2,I,J),W(2,I,J),P(2,I,J),RM(1,I,J),DXDL(2,I,J),I=1,100),I=1,100)	BRA 810
1	I=1,100	BRA 820
2	J=1,100	BRA 830
	WRITE (6,230) KK	BRA 840
	IF (KK.EQ.NSTART) GO TO 130	BRA 850
	IF (KK.EQ.N) GO TO 120	BRA 860
	CALL ERRORS (4)	BRA 870
120	CONTINUE	BRA 880
	WRITE (6,240)	BRA 890
	GO TO 210	BRA 900
C		BRA 910
C	BACKSPACE AND REREAD PLACES TO START INTEGRATION	BRA 920
C		BRA 930
130	BACKSPACE 7	BRA 940
	BACKSPACE 7	BRA 950
	READ (7) KK,X(2),MM,NVN,SAFTY,DELXMM,DELX,RPASS,((Y(2,I,J),Z(2,I,J),U(2,I,J),V(2,I,J),W(2,I,J),P(2,I,J),RM(1,I,J),DXDL(2,I,J),I=1,100),I=1,100)	BRA 960
	2(I),J=1,100)	BRA 970
	CUDELX=DELX	BRA 980
	READ (7) KK,X(1),MM,NVN,SAFTY,DELXMM,DELX,RPASS,((Y(1,I,J),Z(1,I,J),U(1,I,J),V(1,I,J),W(1,I,J),P(1,I,J),RM(2,I,J),DXDL(1,I,J),I=1,100),I=1,100)	BRA 990
	2(I),J=1,100)	BRA 1000
	EXCNTR=0	BRA 1010
	L=2	BRA 1020
	LL=1	BRA 1030
C		BRA 1040
C		BRA 1050
C	CALCULATE THRUST DATA AND PRINT INITIAL VALUE SURFACE	BRA 1060
		BRA 1070
	CALL THRUST	BRA 1080
	CALL PRNOUT	BRA 1090
		BRA 1100

140	L=1	BKA1110
	LL=2	BKA1120
	IF (INSTART.LT.0) GO TO 150	BKA1130
	NSTART=NSTART+1	BKA1140
	MSTART=NSTART	BKA1150
	GO TO 160	BKA1160
C		BKA1170
150	MSTART=1	BKA1180
160	DO 200 KK=MSTART,100	BKA1190
	X(LL)=X(L)+DELX	BKA1200
C		BKA1210
C	SEE IF END OF NOZZLE HAS BEEN REACHED	BKA1220
C		BKA1230
	IF (X(LL).EQ.XMAX) GO TO 210	BKA1240
	IF (X(LL).GT.XMAX) GO TO 170	BKA1250
	GO TO 180	BKA1260
C		BKA1270
170	X(LL) XMAX	BKA1280
	DELX=XM (-X(L))	BKA1290
180	CONTINUE	BKA1300
C		BKA1310
C	INTEGRATE OVER BOUNDARIES AND INTERIOR	BKA1320
C		BKA1330
	CALL BOUND	BKA1340
	CALL INTER	BKA1350
C		BKA1360
C	CALCULATE NEW XSTEP	BKA1370
C		BKA1380
	CALL XRGLT1 (L,LL,I,J)	BKA1390
C		BKA1400
C	CALCULATE THRUST PARAMETERS	BKA1410
C		BKA1420
	CALL THRUST	BKA1430
C		BKA1440
C	REFLECT POINTS ALONG PLANES OF SYMMETRY	BKA1450
C		BKA1460
	IF (ICLASS.LT.4) CALL REFLECT (LL)	BKA1470
	IF (INSTART.LT.0) GO TO 190	BKA1480
	WRITE (7) KK,X(LL),MMM,MMN,SAFTY,DELXMM,DELX,RMASS,((Y(LL,I,J),RMA1490	
1	Z(LL,I,J),U(LL,I,J),V(LL,I,J),W(LL,I,J),P(LL,I,J),RM(L,I,J),DXDBKA1500	
2	L(LL,I,J),I=1,111),J=1,111)	BKA1510
C		BKA1520
C	PRINT OUT SOLUTION SURFACE	BKA1530
C		BKA1540
190	CALL PRNOUT	BKA1550
C		BKA1560
C	FLIP INDICIES FOR SOLUTION AND INITIAL VALUE SURFACES	BKA1570
C		BKA1580
	LLL=LL	BKA1590
	LL=L	BKA1600
200	L=LLL	BKA1610
210	IF (INSTART.LT.0) RETURN	BKA1620
	REWIND 7	BKA1630
	RETURN	BKA1640
C		BKA1650
C		BKA1660
220	FG=HAY (110,10X,11MBEGIN TAPE SEARCH FOR START PLANE,2X,11)	BKA1670
230	FORMAT (11,10X,6HPLANE,11,1X,14HREAD FROM TAPE)	BKA1680
240	FORMAT (110,10X,11HTAPE SEARCH EXCEEDED,100 PLANS)	BKA1690
	END	BKA1700

```

618FTC INTERP
SUBROUTINE INTERP
C
C *****
C
C A SECOND ORDER INTERPOLATION POLYNOMIAL  $F(Y,Z) = A1 + A2*Y + A3*Z +$ 
C  $A4*Y*Z + A5*Y**2 + A6*Z**2$  IS CONSTRUCTED BY LEAST SQUARES FIT.
C NINE NEIGHBORING POINTS ARE USED FOR FITTING THE SIX DEPENDENT
C VARIABLES U, V, W, P, PT AND H.
C *****
C
C DIMENSION IK(9,9), JK(9,9)
C COMMON /SOLUTN/ Y(2,19,19), Z(2,19,19), L(2,19,19), V(2,19,19), W(2,19,19),
1,19), P(2,19,19), PT(19,19), H(19,19), KCLASS(19,19)
C COMMON /XRGIT/ RM(2,19,19), OXOL(2,19,19), EXCNTR, DELXMN, PMM, NAN, SAFTAP
1TY
C COMMON /CNTRL/ PRINT1, PRINT2, EKRR, IVSTYP, ICLASS, NP, NT, II, JJ, L, LL,
INSTART, DELX, ODELX, KK, X(2), XMAX, NO
C COMMON /INTRP/ B(6,6)
C COMMON /SLAS/ A(21)
C
C INDICES STENCIL DATA
C
C DATA IK/0,0,0,1,1,1,2,2,2,0,0,0,0,1,1,1,1,2,0,0,0,0,1,1,1,2,0,0,TRP 240
10,0,0,1,1,1,2,0,-1,0,-1,-1,1,0,1,1,0,-1,0,-1,1,0,1,1,2,0,-1,0,-1,TRP 250
2,2,0,1,0,0,0,0,-1,-1,-2,1,1,2,0,-1,1,-1,0,1,-1,0,1,1,TRP 260
C DATA JK/0,1,2,0,1,2,0,1,2,0,-1,1,2,-1,0,1,2,2,0,-2,-1,1,2,0,1,2,2,TRP 270
10,-2,-1,1,2,-1,0,1,0,0,-2,-1,-1,0,0,1,1,2,0,-1,-1,0,0,1,1,2,1,0,-1,TRP 280
2,-1,0,0,0,1,1,2,0,-2,2,-1,1,0,-1,1,0,0,0,0,1,1,1,-1,-1,1,TRP 290
C INTEGER PRINT1, PRINT2
C M=II
C N=JJ
C
C ZERO SUMMING LOCATIONS
C
C DO 10 I=1,21
10 A(I)=0.0
C DO 20 J=1,6
20 B(I,J)=0.0
C
C DETERMINE PARAMETERS FOR STENCIL MANIPULATION FROM KCLASS LABELS
C
C PICK=KCLASS(M,N)
C NPICK=PICK/10.0
C NPTYP=KCLASS(M,N)-NPICK*10
C A(1)=9.0
C
C MANIPULATION OF INDICES FOR 9 POINT STENCIL
C
C DO 150 K=1,9
C DO 10 I30,40,50,60,70,80,90,100), NPICK
30 I=IK(K,NPTYP)
J=JK(K,NPTYP)

```

	GO TO 110	TRP 550
C		TRP 560
40	I=JK(K,NPTYP)	TRP 570
	J=IK(K,NPTYP)	TRP 580
	GO TO 110	TRP 590
C		TRP 600
50	I=-JK(K,NPTYP)	TRP 610
	J=IK(K,NPTYP)	TRP 620
	GO TO 110	TRP 630
C		TRP 640
60	I=-IK(K,NPTYP)	TRP 650
	J=JK(K,NPTYP)	TRP 660
	GO TO 110	TRP 670
C		TRP 680
	I=-IK(K,NPTYP)	TRP 690
	J=-JK(K,NPTYP)	TRP 700
	GO TO 110	TRP 710
C		TRP 720
80	I=-JK(K,NPTYP)	TRP 730
	J=-IK(K,NPTYP)	TRP 740
	GO TO 110	TRP 750
C		TRP 760
90	I=JK(K,NPTYP)	TRP 770
	J=-IK(K,NPTYP)	TRP 780
	GO TO 110	TRP 790
C		TRP 800
100	I=IK(K,NPTYP)	TRP 810
	J=JK(K,NPTYP)	TRP 820
110	I=+M	TRP 830
	J=+N	TRP 840
C		TRP 850
C	SEARCH FOR NEAREST NEIGHBOR FOR XSTEP REGULATION	TRP 860
C		TRP 870
	RS=(Y(L,I,J)-Y(L,M,N))**2+(Z(L,I,J)-Z(L,M,N))**2	TRP 880
	GO TO (140,130,120,120,120-120,120,120,120), K	TRP 890
120	IF (RS-RSM) 130,140,140	TRP 900
130	RSM=RS	TRP 910
140	CONTINUE	TRP 920
C		TRP 930
C	CALCULATE LEAST SQUARE VECTORS FOR THE DEPENDENT VARIABLES	TRP 940
C	U, V, W, P, PT, R	TRP 950
C		TRP 960
	B(1,1)=B(1,1)+U(L,I,J)	TRP 970
	B(2,1)=B(2,1)+U(L,I,J)*Y(L,I,J)	TRP 980
	B(3,1)=B(3,1)+U(L,I,J)*Z(L,I,J)	TRP 990
	B(4,1)=B(4,1)+U(L,I,J)*Y(L,I,J)*Z(L,I,J)	TRP1000
	B(5,1)=B(5,1)+U(L,I,J)*Y(L,I,J)**2	TRP1010
	B(6,1)=B(6,1)+U(L,I,J)*Z(L,I,J)**2	TRP1020
	B(1,2)=B(1,2)+V(L,I,J)	TRP1030
	B(2,2)=B(2,2)+V(L,I,J)*Y(L,I,J)	TRP1040
	B(3,2)=B(3,2)+V(L,I,J)*Z(L,I,J)	TRP1050
	B(4,2)=B(4,2)+V(L,I,J)*Y(L,I,J)*Z(L,I,J)	TRP1060
	B(5,2)=B(5,2)+V(L,I,J)*Y(L,I,J)**2	TRP1070
	B(6,2)=B(6,2)+V(L,I,J)*Z(L,I,J)**2	TRP1080
	B(1,3)=B(1,3)+W(L,I,J)	TRP1090
	B(2,3)=B(2,3)+W(L,I,J)*Y(L,I,J)	TRP1100

B(3,3)=B(3,3)+W(L,I,J)*Z(L,I,J)	TRP1110
B(4,3)=B(4,3)+W(L,I,J)*Y(L,I,J)*Z(L,I,J)	TRP1120
B(5,3)=B(5,3)+W(L,I,J)*Y(L,I,J)**2	TRP1130
B(6,3)=B(6,3)+W(L,I,J)*Z(L,I,J)**2	TRP1140
B(1,4)=B(1,4)+P(L,I,J)	TRP1150
B(2,4)=B(2,4)+P(L,I,J)*Y(L,I,J)	TRP1160
B(3,4)=B(3,4)+P(L,I,J)*Z(L,I,J)	TRP1170
B(4,4)=B(4,4)+P(L,I,J)*Y(L,I,J)*Z(L,I,J)	TRP1180
B(5,4)=B(5,4)+P(L,I,J)*Y(L,I,J)**2	TRP1190
B(6,4)=B(6,4)+P(L,I,J)*Z(L,I,J)**2	TRP1200
B(1,5)=B(1,5)+PT(I,J)	TRP1210
B(2,5)=B(2,5)+PT(I,J)*Y(L,I,J)	TRP1220
B(3,5)=B(3,5)+PT(I,J)*Z(L,I,J)	TRP1230
B(4,5)=B(4,5)+PT(I,J)*Y(L,I,J)*Z(L,I,J)	TRP1240
B(5,5)=B(5,5)+PT(I,J)*Y(L,I,J)**2	TRP1250
B(6,5)=B(6,5)+PT(I,J)*Z(L,I,J)**2	TRP1260
B(1,6)=B(1,6)+H(I,J)	TRP1270
B(4,6)=B(4,6)+H(I,J)*Y(L,I,J)*Z(L,I,J)	TRP1300
B(5,6)=B(5,6)+H(I,J)*Y(L,I,J)**2	TRP1310
B(6,6)=B(6,6)+H(I,J)*Z(L,I,J)**2	TRP1320
B(2,5)=B(2,5)+H(I,J)*Y(L,I,J)	TRP1280
B(3,6)=B(3,6)+H(I,J)*Z(L,I,J)	TRP1290
C	TRP1330
C	TRP1340
C	TRP1350
150	TRP1360
	TRP1370
	TRP1380
	TRP1390
	TRP1400
	TRP1410
	TRP1420
	TRP1430
	TRP1440
	TRP1450
	TRP1460
	TRP1470
	TRP1480
	TRP1490
	TRP1500
	TRP1510
	TRP1520
	TRP1530
	TRP1540
	TRP1550
	TRP1560
	TRP1570
	TRP1580
	TRP1590
	TRP1600
	TRP1610
	TRP1620

```

C
C
C
CALCULATE THE LEAST SQUARE MATRIX FOR Y, Z COORDINATES
A(2)=A(2)+Y(L,I,J)
A(4)=A(4)+Z(L,I,J)
A(7)=A(7)+Y(L,I,J)*Z(L,I,J)
A(11)=A(11)+Y(L,I,J)**2
A(15)=A(15)+Z(L,I,J)**2
A(8)=A(8)+Y(L,I,J)**2+Z(L,I,J)
A(12)=A(12)+Y(L,I,J)*Z(L,I,J)
A(17)=A(17)+Y(L,I,J)*Z(L,I,J)**2
A(18)=A(18)+Z(L,I,J)**2
A(10)=A(10)+Y(L,I,J)**2+Z(L,I,J)**2
A(14)=A(14)+Y(L,I,J)*Z(L,I,J)
A(19)=A(19)+Y(L,I,J)*Z(L,I,J)**3
A(15)=A(15)+Y(L,I,J)**4
150 A(21)=A(21)+Z(L,I,J)**4
A(3)=A(11)
A(5)=A(7)
A(6)=A(16)
A(9)=A(17)
A(13)=A(8)
A(20)=A(10)
RM(L,M,N)=SQRT(RSM)
C
C
C
SOLVE LEAST SQUARE SYSTEM FOR THE POLYNOMIAL COEFFICIENTS
CALL SLAES
RETURN
END

```

LIBRARY SLAES	SLA 10
SUBROUTINE SLAES	SLA 20
C *****	SLA 30
C *****	SLA 40
C MODIFICATION OF IBM LIBRARY SUBROUTINE GELS FOR A SIXTH ORDER SYSTEM	SLA 50
C OF SYMMETRIC LINEAR EQUATIONS - USED BY INTERP	SLA 60
C *****	SLA 70
C *****	SLA 80
C	SLA 90
DIMENSION AUX(5)	SLA 100
COMMON /SLAS/ A(21)	SLA 110
COMMON /INTRP/ R(36)	SLA 120
N=6	SLA 130
N=6	SLA 140
C	SLA 150
C SEARCH FOR GREATEST MAIN DIAGONAL ELEMENT	SLA 160
C	SLA 170
PIV=0.	SLA 180
L=0	SLA 190
DO 20 K=1,M	SLA 200
L=L+K	SLA 210
TB=ABS(A(L))	SLA 220
IF (TB-PIV) 20,20,10	SLA 230
10        PIV=TB	SLA 240
I=L	SLA 250
J=K	SLA 260
20    CONTINUE	SLA 270
C	SLA 280
C MAIN DIAGONAL ELEMENT A(I)=A(J,J) IS FIRST PIVOT ELEMENT.	SLA 290
C PIV CONTAINS THE ABSOLUTE VALUE OF A(I).	SLA 300
C	SLA 310
C	SLA 320
C START ELIMINATION LOOP	SLA 330
C	SLA 340
LST=0	SLA 350
NM=N*M	SLA 360
LEND=M-1	SLA 370
DO 130 K=1,M	SLA 380
LT=J-K	SLA 390
LST=LST+K	SLA 400
C	SLA 410
C PIVOT ROW REDUCTION AND ROW INTERCHANGE IN RIGHT HAND SIDE R	SLA 420
C	SLA 430
PIV=1./A(I)	SLA 440
DO 30 L=K,NM,M	SLA 450
LL=L+LT	SLA 460
TB=PIV*A(LL)	SLA 470
R(LL)=R(L)	SLA 480
30    R(L)=TB	SLA 490
C	SLA 500
C IS ELIMINATION TERMINATED	SLA 510
C	SLA 520
IF (K-M) 40,140,140	SLA 530
C	SLA 540

C	ROW AND COLUMN INTERCHANGE AND PIVOT ROW REDUCTION IN MATRIX A.	SLA 550
C	ELEMENTS OF PIVOT COLUMN ARE SAVED IN AUXILIARY VECTOR AUX.	SLA 560
C		SLA 570
40	LR=LST+(LT*(K+J-1))/2	SLA 580
	LL=LR	SLA 590
	L=LST	SLA 600
	DO 90 II=K,LEND	SLA 610
	L=L+1	SLA 620
	LL=LL+1	SLA 630
	IF (L-LR) 70,50,60	SLA 640
50	A(LL)=A(LST)	SLA 650
	TB=A(LL)	SLA 660
	GO TO 80	SLA 670
C		SLA 680
60	LL=L+LT	SLA 690
70	TB=A(LL)	SLA 700
	A(LL)=A(L)	SLA 710
80	AUX(II)=TB	SLA 720
90	A(LL)=PIV/TB	SLA 730
C		SLA 740
C	SAVE COLUMN INTERCHANGE INFORMATION	SLA 750
C		SLA 760
	A(LST)=LT	SLA 770
C		SLA 780
C	ELEMENT REDUCTION AND SEARCH FOR NEXT PIVOT	SLA 790
C		SLA 800
	PIV=0.	SLA 810
	LLST=LST	SLA 820
	LT=0	SLA 830
	DO 130 II=K,LEND	SLA 840
	PIV=-AUX(II)	SLA 850
	LL=LLST	SLA 860
	LT=LT+1	SLA 870
	DO 100 LLD=II,LEND	SLA 880
	LL=LL+LLD	SLA 890
	L=LL+LT	SLA 900
100	A(L)=A(L)+PIV*A(LL)	SLA 910
	LLST=LLST+II	SLA 920
	LR=LLST+LT	SLA 930
	TB=ABS(A(LR))	SLA 940
	IF (TB-PIV) 120,120,110	SLA 950
110	PIV=TB	SLA 960
	I=LR	SLA 970
	J=II+1	SLA 980
120	DO 130 LR=K,NM,M	SLA 990
	LL=LR+LT	SLA1000
130	R(LL)=R(LL)+PIV*R(LR)	SLA1010
C		SLA1020
C	END OF ELIMINATION LCOP	SLA1030
C		SLA1040
C		SLA1050
C	BACK SUBSTITUTION AND BACK INTERCHANGE	SLA1060
C		SLA1070
140	II=M	SLA1080
	DO 160 I=2,M	SLA1090
	LST=LST-II	SLA1100

```

      II=II-1
      L=A(LST)+.5
CO 160 J=II,NM,M
      TB=R(J)
      LL=J
      K=LST
      DO 150 LT=II,LEND
        LL=LL+1
        K=K+LT
150    TB=TB-A(K)*R(LL)
        K=J+L
        R(J)=R(K)
160    R(K)=TB
      RETURN
      END

```

```

SLA1110
SLA1120
SLA1130
SLA1140
SLA1150
SLA1160
SLA1170
SLA1180
SLA1190
SLA1200
SLA1210
SLA1220
SLA1230
SLA1240
SLA1250-

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*IBFTC XRGLTR
SUBROUTINE XRGLTR (I,II,M,N)
C
C *****
C SEARCHES FOR THE MOST RESTRICTIVE POINT ON THE SOLUTION SURFACE
C AND PREDICTS NEW XSTEP SIZE
C *****
C
COMMON /XRGTRY/ RM(2,19,19),DXDL(2,19,19),EXCNTR,DELXMN,MMM,NNN,SAF
1TY
COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,JJ,L,LL,
INSTART,DELX,ODELX,KK,X(2),XMAX,NO
INTEGER PRINT1,PRINT2
C
C CALCULATE THE AVERAGE STEP SIZE
C
DELXB=0.5*(DXDL(I,M,N)+DXDL(II,M,N))*RM(I,M,N)
IF (DELXB.GE.DELX) GO TO 10
10 IF (DELXB.GE.DELXMN) GO TO 20
DELXMN=DELXB
C
C LABELS FOR MOST RESTRICTIVE POINT
C
MMM=M
NNN=N
20 RETURN
C
C PREDICT NEW XSTEP
C
ENTRY XRGLTR(I,II,M,N)
C
C ADJUST SAFETY FACTOR
C
RATIO=DELXMN/DELX
IF (RATIO.GT.1.1) RATIO=1.1
IF (RATIO.LT.0.9) RATIO=0.9
SAFETY=SAFETY*RATIO
DELXEX=DXDL(II,MMM,NNN)*RM(II,MMM,NNN)+DELX/ODELX*(DXDL(II,MMM,NNN)
1*RM(II,MMM,NNN)-DXDL(I,MMM,NNN)*RM(I,MMM,NNN))
C
C ROUND OFF DELX
C
NDELX=1000.0*DELXEX*SAFETY
DELXEX=NDELX
DELXEX=DELXEX/1000.0
DELXMN=DELXEX*2.0
COFLX=DELX
DELX=DELXEX
RETURN
END
XRG 10
XRG 20
XRG 30
XRG 40
XRG 50
XRG 60
XRG 70
XRG 80
XRG 90
XRG 100
XRG 110
XRG 120
XRG 130
XRG 140
XRG 150
XRG 160
XRG 170
XRG 180
XRG 190
XRG 200
XRG 210
XRG 220
XRG 230
XRG 240
XRG 250
XRG 260
XRG 270
XRG 280
XRG 290
XRG 300
XRG 310
XRG 320
XRG 330
XRG 340
XRG 350
XRG 360
XRG 370
XRG 380
XRG 390
XRG 400
XRG 410
XRG 420
XRG 430
XRG 440
XRG 450
XRG 460
XRG 470
XRG 480
XRG 490
XRG 500
XRG 510-

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$ORIGIN      C
$IBFTC $OU:DR
      SUBROUTINE BOUNDR
C
C *****
C
C INTEGRATES OVER THE BOUNDARY POINTS
C *****
C
      COMMON /SOLUTN/ Y(2,19,19),Z(2,19,19),U(2,19,19),V(2,19,19),W(2,19,19),P(2,19,19),PT(19,19),H(19,19),KCLASS(19,19)
      COMMON /XRGLT/ RM(2,19,19),DXDL(2,19,19),EXCFLR,DELMXN,PPM,AAA,SAFBOU
      ITY
      COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,JJ,L,LL,BOU
      INSTART,DELX,ODELX,KK,X(2),XMAX,NO
      NT1=NT-1
      NO2=NO
      IF (ICLASS.EQ.3) NO2=NP
      DO 10 I=1,NO,NT1
      DO 10 J=1,NO2
      II=I
      JJ=J
      CALL BPTSUB (Y(LL,I,J),Z(LL,I,J),PT(I,J),H(I,J),Y(LL,I,J),Z(LL,I,J),U(LL,I,J),V(LL,I,J),W(LL,I,J),P(LL,I,J),DXDL(LL,I,J))
10  CALL XRGLTR (L,LL,I,J)
      IF (ICLASS.EQ.1) GO TO 30
      NO1=NO
      IF (ICLASS.GT.2) NO1=NO-1
      DO 20 J=1,NO2,NT1
      DO 20 I=2,NO1
      II=I
      JJ=J
      CALL BPTSUB (Y(LL,I,J),Z(LL,I,J),PT(I,J),H(I,J),Y(LL,I,J),Z(LL,I,J),U(LL,I,J),V(LL,I,J),W(LL,I,J),P(LL,I,J),DXDL(LL,I,J))
20  CALL XRGLTR (L,LL,I,J)
30  CONTINUE
      RETURN
      END
BOU  1)
BOU  2)
BOU  3)
BOU  4)
BOU  5)
BOU  6)
BOU  7)
BOU  8)
BOU  9)
BOU 100
BOU 110
BOU 120
BOU 130
BOU 140
BOU 150
BOU 160
BOU 170
BOU 180
BOU 190
BOU 200
BOU 210
BOU 220
BOU 230
BOU 240
BOU 250
BOU 260
BOU 270
BOU 280
BOU 290
BOU 300
BOU 310
BOU 320
BOU 330
BOU 340
BOU 350
BOU 360
BOU 370-

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816F1C BPYSUB
      SUBROUTINE BPTSUB (Y5,Z5,PT5,H5,Y6,Z6,C6,V6,W6,P5,DXDL)      BPT 10
C                                          BPT 20
C      *****                                          BPT 30
C                                          BPT 40
C      CALCULATES A NEW BOUNDARY POINT OF THE FLOW FROM DATA STORED IN THE BPT 50
C      THREE-DIMENSIONAL ARRAYS U, V, W, P, PT AND H AND BOUNDARY DATA BPT 60
C      FROM THE WALL POINT SUBROUTINE, WALSLB.                      BPT 70
C                                          BPT 80
C      *****                                          BPT 90
C                                          BPT 100
C      COMMON /PYSUB/ Y(6),Z(6),U(6),V(6),W(6),P(6),PT(6),H(6),A(6),RO(6) BPT 110
C      1,C(6),Q(6),QSQR(6),DUOX(6),DUOY(6),DUOZ(6),DVOX(6),DVODY(6),CVDZ(6) BPT 120
C      2,DUOX(6),DUOY(6),DUOZ(6),DPOX(6),DPOY(6),DPOZ(6),DPTDX(6),DPTDY(6) BPT 130
C      3,DPTDZ(6),DMOX(6),DMCY(6),DMOZ(6),DCOX(6),DCDY(6),DCOZ(6),DADP(6),BPT 140
C      4,DADH(6),DADPT(6),DROCP(6),DRODP(6),DRODH(6),ALPX(6),ALPY(6),ALPZ(6) BPT 150
C      56),BETX(6),BETY(6),BETZ(6),ALPTX(6),ALPTY(6),ALPTZ(6),CPTH(6),UPTH BPT 160
C      6(4),VPTH(4),WPTH(4),UTHET(4),VTHET(4),WTHET(4),TAU(6),ADBD%      BPT 170
C      COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,N7,II,JJ,L,LL, BPT 180
C      1,START,DELX,DELX,KK,X(2),XMAX,N,                                          BPT 190
C      COMMON /INTRP/ B(6,6)                                          BPT 200
C      REAL NEUM,K1,K2,NORM                                          BPT 210
C      INTEGER PRNT1,PRNT2                                          BPT 220
C      Y(5)=Y5                                          BPT 230
C      Z(5)=Z5                                          BPT 240
C      PT(5)=PT5                                          BPT 250
C      H(5)=H5                                          BPT 260
C      CALL INTERP                                          BPT 270
C                                          BPT 280
C      INTERPOLATE FOR VALUES AT POINT (5)                                          BPT 290
C                                          BPT 300
C      U(5)=B(1,1)+B(2,1)*Y(5)+B(3,1)*Z(5)+B(4,1)*Y(5)*Z(5)+B(5,1)*Y(5)* BPT 310
C      12+B(6,1)*Z(5)**2                                          BPT 320
C      V(5)=B(1,2)+B(2,2)*Y(5)+B(3,2)*Z(5)+B(4,2)*Y(5)*Z(5)+B(5,2)*Y(5)* BPT 330
C      12+B(6,2)*Z(5)**2                                          BPT 340
C      W(5)=B(1,3)+B(2,3)*Y(5)+B(3,3)*Z(5)+B(4,3)*Y(5)*Z(5)+B(5,3)*Y(5)* BPT 350
C      12+B(6,3)*Z(5)**2                                          BPT 360
C      P(5)=B(1,4)+B(2,4)*Y(5)+B(3,4)*Z(5)+B(4,4)*Y(5)*Z(5)+B(5,4)*Y(5)* BPT 370
C      12+B(6,4)*Z(5)**2                                          BPT 380
C                                          BPT 390
C      CALCULATE PARTIAL DERIVATIVES FOR THE DEPENDENT VARIABLES BPT 400
C                                          BPT 410
C      DUOY(5)=B(2,1)+B(4,1)*Z(5)+2.0*B(5,1)*Y(5) BPT 420
C      DUOZ(5)=B(3,1)+B(4,1)*Y(5)+2.0*B(6,1)*Z(5) BPT 430
C      CVDY(5)=B(2,2)+B(4,2)*Z(5)+2.0*B(5,2)*Y(5) BPT 440
C      CVDZ(5)=B(3,2)+B(4,2)*Y(5)+2.0*B(6,2)*Z(5) BPT 450
C      CWDY(5)=B(2,3)+B(4,3)*Z(5)+2.0*B(5,3)*Y(5) BPT 460
C      CWDZ(5)=B(3,3)+B(4,3)*Y(5)+2.0*B(6,3)*Z(5) BPT 470
C      CPDY(5)=B(2,4)+B(4,4)*Z(5)+2.0*B(5,4)*Y(5) BPT 480
C      CPDZ(5)=B(3,4)+B(4,4)*Y(5)+2.0*B(6,4)*Z(5) BPT 490
C                                          BPT 500
C      CALCULATE THERMODYNAMIC PROPERTIES AT POINT (5) BPT 510
C                                          BPT 520
C      CALL AROSUB (P(5),PT(5),H(5),A(5),RO(5),QSQR(5),DADP(5),DADPT(5),DBPT 530
C      1ADH(5),DRODP(5),DRODPT(5),DRODH(5)) BPT 540

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C      C(5)=SQRT(A(5)**2+QSQR(5)/(45QW(5)-A(5)**2))      BPT 550
C      CUOX(5)=(RO(5)*U(5)*(V(5)*DUY(5)+W(5)*UDZ(5))-V(5)*DPDY(5)-W(5)*BPT 560
      DCPDZ(5)-RO(5)*A(5)**2*(DVOY(5)+QWZ(5)))/(RO(5)*(A(5)**2-U(5)**2))BPT 570
C      CVOX(5)=(-DPDY(5)-RO(5)*V(5)+DVOY(5)-RO(5)*W(5)*DVDZ(5))/(RC(5)*U(BPT 580
      5))      BPT 590
C      DWDX(5)=(-DCPDZ(5)-RO(5)*V(5)*DWDY(5)-RO(5)*W(5)*DWDZ(5))/(RO(5)*U(BPT 600
      5))      BPT 610
C      UUD5=U(5)*(U(5)*CUOX(5)+V(5)*(DVOX(5)+DUY(5))+W(5)*(DWDX(5)+CUOZ(BPT 620
      5))+V(5)*(V(5)*DVOY(5)+W(5)*(DWDY(5)+DVDZ(5))+W(5)*W(5)*QWZ(5))BPT 630
      ADBD5=CUOX(5)+DVOY(5)+DWDZ(5)-UUD5/QSQR(5)      BPT 640
C      MAKE TAYLOR SERIES APPROXIMATION TO NEW POINT DEPENDENT VARIABLES      BPT 650
C      DPOX(5)=-RC(5)*(U(5)*DUOX(5)+V(5)*CUDY(5)+W(5)*DUDZ(5))      BPT 660
C      DELX=DELX*V(5)/U(5)      BPT 670
C      DELZ=DELX*W(5)/U(5)      BPT 680
C      P(6)=P(5)+(DPOX(5)*DELX+DPDY(5)*DELY+DPOZ(5)*DELZ)/3.0      BPT 690
C      INITIALIZE LOOP VALUES IF STATIC PRESSURE ESTIMATE IS NEGATIVE      BPT 700
C      IF (P(6)) 10,10,20      BPT 710
10      U(6)=U(5)      BPT 720
      V(6)=V(5)      BPT 730
      W(6)=W(5)      BPT 740
      C(6)=C(5)      BPT 750
      QSQR(6)=QSQR(5)      BPT 760
      RO(6)=RO(5)      BPT 770
      P(6)=P(5)      BPT 780
      GO TO 30      BPT 790
C      INITIALIZE LOOP VALUES IF PRESSURE ESTIMATE IS POSITIVE      BPT 800
C      CALL AROSBI (P(6),PT(5),H(5),A(6),RO(6),QSQR(6))      BPT 810
20      C(6)=SQRT(A(6)**2+QSQR(6)/(QSQR(6)-A(6)**2))      BPT 820
      U(6)=U(5)+DUOX(5)*DELX+DUY(5)*DELY+UDZ(5)*DELZ      BPT 830
      V(6)=V(5)+DVOX(5)*DELX+DVOY(5)*DELY+DVDZ(5)*DELZ      BPT 840
      W(6)=W(5)+DWDX(5)*DELX+DWDY(5)*DELY+DWDZ(5)*DELZ      BPT 850
      QS=U(6)**2+V(6)**2+W(6)**2      BPT 860
      RATIO=SQRT(QSQR(6)/QS)      BPT 870
      U(6)=RATIO*U(6)      BPT 880
      V(6)=RATIO*V(6)      BPT 890
      W(6)=RATIO*W(6)      BPT 900
30      XS=X(L)      BPT 910
C      OBTAIN OUTER NORMAL AT POINT(5)      BPT 920
C      CALL WALSB1 (XS,Y5,Z5,BETX(6),BETY(6),BETZ(6))      BPT 930
      ASSIGN 40 TO NNN      BPT 940
      DO 270 N=1,20      BPT 950
C      FIND COORDINATES OF NEW POINT FOR ITH ITERATION      BPT 960
      BPT 970
      BPT 980
      BPT 990
      BPT 1000
      BPT 1010
      BPT 1020
      BPT 1030
      BPT 1040
      BPT 1050
      BPT 1060
      BPT 1070
      BPT 1080
      BPT 1090
      BPT 1100

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C      TAU(5)=-2.0*DELX/(U(5)+U(6))
      Y(6)=Y(5)-(V(6)+V(5))*TAU(5)/2.C
      Z(6)=Z(5)-(W(6)+W(5))*TAU(5)/2.C
C
C      OBTAIN WALL POINT COORDINATES AND OUTER NORMAL AT POINT (6)
C
      CALL WALSUB (XILL,Y(6),Z(6),HETX(6),BETX(6),BETZ(6))
      ALPHAX=BETX(6)*W(6)-BETZ(6)*V(6)
      ALPHAY=BETZ(6)*U(6)-HETX(6)*W(6)
      ALPHAZ=BETX(6)*V(6)-BETX(6)*U(6)
      DENC=SQRT (ALPHAX**2+ALPHAY**2+ALPHAZ**2)
      ALPX(6)=ALPHAX/DENC
      ALPY(6)=ALPHAY/DENC
      ALPZ(6)=ALPHAZ/DENC
C
      DET4=BETX(6)*(ALPY(6)*W(6)-V(6)*ALPZ(6))-ALPX(6)*(BETX(6)*W(6)-
1      V(6)*BETZ(6))+U(6)*(BETX(6)*ALPZ(6)-ALPY(6)*BETZ(6))
      DET1=ALPY(6)*W(6)-V(6)*ALPZ(6)
      DET2=BETX(6)*ALPZ(6)-ALPY(6)*HETZ(6)
      DET3=ALPX(6)*W(6)-J(6)*ALPZ(6)
      DET4=BETX(6)*ALPZ(6)-ALPX(6)*HETZ(6)
      DET5=ALPX(6)*V(6)-J(6)*ALPY(6)
      DET6=BETX(6)*ALPY(6)-ALPX(6)*HETX(6)
      DO 260 J=1,3
C
      GO TO A74, (40,5)
C
C      INITIALIZE INDEX LOOP
C
40      U(J)=U(5)
      V(J)=V(5)
      W(J)=W(5)
      C(J)=C(5)
      ALPX(J)=ALPX(6)
      ALPY(J)=ALPY(6)
      ALPZ(J)=ALPZ(6)
      HETX(J)=HETX(6)
      BETX(J)=BETX(6)
      BETZ(J)=BETZ(6)
C
C      CALCULATE TAU(J) FOR ITH ITERATION
C
90      GO TO (60,70,80), J
C
60      CALPH=C(6)*ALPX(6)+C(1)*ALPX(1)
      GO TO 90
C
70      CALPH=C(6)*BETX(6)+C(2)*BETX(2)
      GO TO 90
C
80      CALPH=-C(6)*ALPX(6)-C(3)*ALPX(3)
      TAU(J)=2.0*(-DELX)/(U(6)+U(J))+CALPH
C
C      CALCULATE Y(U) FOR THE ITH ITERATION
C

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BPT1110
BPT1120
BPT1130
BPT1140
BPT1150
BPT1160
BPT1170
BPT1180
BPT1190
BPT1200
BPT1210
BPT1220
BPT1230
BPT1240
BPT1250
BPT1260
BPT1270
BPT1280
BPT1290
BPT1300
BPT1310
BPT1320
BPT1330
BPT1340
BPT1350
BPT1360
BPT1370
BPT1380
BPT1390
BPT1400
BPT1410
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BPT1450
BPT1460
BPT1470
BPT1480
BPT1490
BPT1500
BPT1510
BPT1520
BPT1530
BPT1540
BPT1550
BPT1560
BPT1570
BPT1580
BPT1590
BPT1600
BPT1610
BPT1620
BPT1630
BPT1640
BPT1650
BPT1660

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	GO TO (100,110,120), J	BPT1670
C		BPT1680
100	CALPY=C(6)*ALPY(6)+C(1)*ALPY(1,	BPT1690
	GO TO 130	BPT1700
C		BPT1710
110	CALPY=C(6)*BFTY(6)+C(2)*BFTY(2)	BPT1720
	GO TO 130	BPT1730
C		BPT1740
120	CALPY=-C(6)*ALPY(6)-C(3)*ALPY(3)	BPT1750
	GO TO 130	BPT1760
C		BPT1770
130	Y(J)=Y(6)+IV(6)+V(J)+CALPY)*TAU(J)/2.0	BPT1780
C		BPT1790
C	CALCULATE Z(J) FOR THE ITH ITERATION	BPT1800
C		BPT1810
	GO TO (140,150,160), J	BPT1820
C		BPT1830
140	CALPZ=C(1)*ALPZ(1)+C(6)*ALPZ(6)	BPT1840
	GO TO 170	BPT1850
C		BPT1860
150	CALPZ=C(6)*BETZ(6)+C(2)*BETZ(2)	BPT1870
C		BPT1880
	GO TO 170	BPT1890
C		BPT1900
160	CALPZ=-C(3)*ALPZ(3)-C(6)*ALPZ(6)	BPT1910
170	Z(J)=Z(6)+W(6)+W(J)+CALPZ)*TAU(J)/2.0	BPT1920
C		BPT1930
C	CALCULATE VALUES FOR U, V, W, H, P, PT, AND DERIVATIVES AT BASE	BPT1940
C	POINTS	BPT1950
C		BPT1960
	U(J)=B(1,1)+B(2,1)*Y(J)+B(3,1)*Z(J)+B(4,1)*Y(J)*Z(J)+B(5,1)*	BPT1970
1	Y(J)**2+B(6,1)*Z(J)**2	BPT1980
C		BPT1990
	V(J)=B(1,2)+B(2,2)*Y(J)+B(3,2)*Z(J)+B(4,2)*Y(J)*Z(J)+B(5,2)*	BPT2000
1	Y(J)**2+B(6,2)*Z(J)**2	BPT2010
C		BPT2020
	W(J)=B(1,3)+B(2,3)*Y(J)+B(3,3)*Z(J)+B(4,3)*Y(J)*Z(J)+B(5,3)*	BPT2030
1	Y(J)**2+B(6,3)*Z(J)**2	BPT2040
C		BPT2050
	P(J)=B(1,4)+B(2,4)*Y(J)+B(3,4)*Z(J)+B(4,4)*Y(J)*Z(J)+B(5,4)*	BPT2060
1	Y(J)**2+B(6,4)*Z(J)**2	BPT2070
C		BPT2080
	PT(J)=B(1,5)+B(2,5)*Y(J)+B(3,5)*Z(J)+B(4,5)*Y(J)*Z(J)+B(5,5)*	BPT2090
1	Y(J)**2+B(6,5)*Z(J)**2	BPT2100
C		BPT2110
	H(J)=B(1,6)+B(2,6)*Y(J)+B(3,6)*Z(J)+B(4,6)*Y(J)*Z(J)+B(5,6)*	BPT2120
1	Y(J)**2+B(6,6)*Z(J)**2	BPT2130
C		BPT2140
	DUDY(J)=B(2,1)+B(4,1)*Z(J)+2.0*B(5,1)*Y(J)	BPT2150
	DVDY(J)=B(2,2)+B(4,2)*Z(J)+2.0*B(5,2)*Y(J)	BPT2160
	DWDY(J)=B(2,3)+B(4,3)*Z(J)+2.0*B(5,3)*Y(J)	BPT2170
	DPDY(J)=B(2,4)+B(4,4)*Z(J)+2.0*B(5,4)*Y(J)	BPT2180
	DPTDY(J)=B(2,5)+B(4,5)*Z(J)+2.0*B(5,5)*Y(J)	BPT2190
	DHDY(J)=B(2,6)+B(4,6)*Z(J)+2.0*B(5,6)*Y(J)	BPT2200
	DUDZ(J)=B(3,1)+B(4,1)*Y(J)+2.0*B(6,1)*Z(J)	BPT2210
	DVDZ(J)=B(3,2)+B(4,2)*Y(J)+2.0*B(6,2)*Z(J)	BPT2220

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DWDZ(J)=B(3,3)+B(4,3)*Y(J)+2.0*B(6,3)*Z(J)      BPT2230
DPDZ(J)=B(3,4)+B(4,4)*Y(J)+2.0*B(6,4)*Z(J)      BPT2240
DPTDZ(J)=B(3,5)+B(4,5)*Y(J)+2.0*B(6,5)*Z(J)      BPT2250
DMDZ(J)=B(3,6)+B(4,6)*Y(J)+2.0*B(6,6)*Z(J)      BPT2260
C                                                    BPT2270
C      CALCULATE A, MU AND DERIVATIVES AT BASE POINTS      BPT2280
C      FROM THERMODYNAMIC DATA      BPT2290
C                                                    BPT2300
C      CALL ARGSUB (P(J),PT(J),H(J),A(J),RO(J),QSQR(J),DADP(J),DADP      BPT2310
1      T(J),DADH(J),DRODP(J),DRODP(J),DRODP(J),DRODP(J))      BPT2320
C      C(J)=SQRT((A(J)**2)*QSQR(J)/(QSQR(J)-A(J)**2))      BPT2330
C                                                    BPT2340
C      CALCULATE SPACE DERIVATIVES USING ENTROPY AND ENTHALPY CONDITIONS      BPT2350
C      ALONG STREAMLINE      BPT2360
C                                                    BPT2370
C      DUDX(J)=(RO(J)*U(J)*V(J)*DUDY(J)+RO(J)*U(J)*W(J)*DUDZ(J)-V(J)      BPT2380
1      )*DPDY(J)-W(J)*DPDZ(J)-RO(J)*A(J)**2*(DUDY(J)+DWDZ(J)))/(RO      BPT2390
2      J*(A(J)**2-U(J)**2))      BPT2400
C                                                    BPT2410
C      DVDX(J)=(-DPDY(J)-RO(J)*V(J)*DVDY(J)-RO(J)*W(J)*DVDZ(J))/(RO      BPT2420
1      J*(A(J)**2-U(J)**2))      BPT2430
C                                                    BPT2440
C      DWDX(J)=(-DPDZ(J)-RO(J)*V(J)*DWDY(J)-RO(J)*W(J)*DWDZ(J))/(RO      BPT2450
1      J*(A(J)**2-U(J)**2))      BPT2460
C                                                    BPT2470
C      CPDX(J)=-RO(J)*(J(J)*DUDX(J)+V(J)*DUDY(J)+W(J)*DUDZ(J))      BPT2480
C                                                    BPT2490
C      DMUX(J)=(-V(J)*DMUY(J)-W(J)*DMOZ(J))/U(J)      BPT2500
C                                                    BPT2510
C      CPTDX(J)=(-V(J)*DPTDY(J)-W(J)*DPTDZ(J))/U(J)      BPT2520
C                                                    BPT2530
C      K1=(C(6)**2)/QSQR(6)      BPT2540
C      K2=1.0+K1      BPT2550
C                                                    BPT2560
C      CCDX(J)=C(J)**3*((DADP(J)*CPDX(J)+DADPT(J)*DPTDX(J)+DACH(J)*      BPT2570
1      DMUX(J))/(A(J)**3)-(U(J)*DUDX(J)+V(J)*DVDX(J)+W(J)*DWDX(J))/      BPT2580
2      (QSQR(J)**2))      BPT2590
C                                                    BPT2600
C      CCDY(J)=C(J)**3*((DADP(J)*DPDY(J)+DADPT(J)*DPTDY(J)+DACH(J)*      BPT2610
1      DMUY(J))/(A(J)**3)-(U(J)*DUDY(J)+V(J)*DVDY(J)+W(J)*DWDY(J))/      BPT2620
2      (QSQR(J)**2))      BPT2630
C                                                    BPT2640
C      CCDZ(J)=C(J)**3*((DADP(J)*DPDZ(J)+DADPT(J)*DPTDZ(J)+DACH(J)*      BPT2650
1      DMDZ(J))/(A(J)**3)-(U(J)*DUDZ(J)+V(J)*DVDZ(J)+W(J)*DWDZ(J))/      BPT2660
2      (QSQR(J)**2))      BPT2670
C                                                    BPT2680
C      CALCULATE VARIATION OF ALPHA AND BETA AT BASE POINTS      BPT2690
C                                                    BPT2700
C      GO TO (180,190,200), J      BPT2710
C                                                    BPT2720
180      CPTH(1)=C(6)*(BETX(6)*DCUX(1)+BETY(6)*CCDY(1)+BETZ(6)*CCDZ(1)      BPT2730
1      )      BPT2740
C      UHT=U(6)+C(6)*ALPX(6)      BPT2750
C      VHT=V(6)+C(6)*ALPY(6)      BPT2760
C      WHT=W(6)+C(6)*ALPZ(6)      BPT2770
C                                                    BPT2780

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C      1      UPTH(1)=C(6)*(BETX(6)*DUDX(1)+BETY(6)*DUDY(1)+BETZ(6)*DUOZ(1)BPT2790
      1      ))      BPT2800
      C      VPTH(1)=C(6)*(BETX(6)*DVDX(1)+BETY(6)*DVDY(1)+BETZ(6)*DVDZ(1)BPT2810
      1      ))      BPT2820
      C      WPTH(1)=C(6)*(BETX(6)*DWDX(1)+BETY(6)*DWDY(1)+BETZ(6)*DWDZ(1)BPT2830
      1      ))      BPT2840
      C      GO TO 210      BPT2850
      190      CPTH(2)=C(6)*(-ALPX(6)*DCDX(2)-ALPY(6)*DCDY(2)-ALPZ(6)*DCDZ(2)BPT2860
      1      2))      BPT2870
      UTH(2)=U(6)+C(6)*BFTX(6)      BPT2880
      VTH(2)=V(6)+C(6)*BFTY(6)      BPT2890
      WTH(2)=W(6)+C(6)*BFTZ(6)      BPT2900
      UPTH(2)=C(6)*(-ALPX(6)*DUDX(2)-ALPY(6)*DUDY(2)-ALPZ(6)*DUOZ(2)BPT2910
      1      2))      BPT2920
      VPTH(2)=C(6)*(-ALPX(6)*DVDX(2)-ALPY(6)*DVDY(2)-ALPZ(6)*DVDZ(2)BPT2930
      1      2))      BPT2940
      WPTH(2)=C(6)*(-ALPX(6)*DWDX(2)-ALPY(6)*DWDY(2)-ALPZ(6)*DWDZ(2)BPT2950
      1      2))      BPT2960
      GO TO 210      BPT2970
      C      CPTH(3)=C(6)*(-BETX(6)*DCDX(3)-BETY(6)*DCDY(3)-BETZ(6)*DCDZ(3)BPT2980
      200      3))      BPT2990
      UTH(3)=U(6)-C(6)*ALPX(6)      BPT3000
      VTH(3)=V(6)-C(6)*ALPY(6)      BPT3010
      WTH(3)=W(6)-C(6)*ALPZ(6)      BPT3020
      UPTH(3)=C(6)*(-BETX(6)*DUDX(3)-BETY(6)*DUDY(3)-BETZ(6)*DUOZ(3)BPT3030
      1      3))      BPT3040
      VPTH(3)=C(6)*(-BETX(6)*DVDX(3)-BETY(6)*DVDY(3)-BETZ(6)*DVDZ(3)BPT3050
      1      3))      BPT3060
      C      WPTH(3)=C(6)*(-BETX(6)*DWDX(3)-BETY(6)*DWDY(3)-BETZ(6)*DWDZ(3)BPT3070
      210      3))      BPT3080
      UTHET(J)=UTH(1)*DUDX(J)+VTH(1)*DUDY(J)+WTH(1)*DUOZ(J)      BPT3090
      VTHET(J)=UTH(1)*DVDX(J)+VTH(1)*DVDY(J)+WTH(1)*DVDZ(J)      BPT3100
      WTHET(J)=UTH(1)*DWDX(J)+VTH(1)*DWDY(J)+WTH(1)*DWDZ(J)      BPT3110
      B3=-(U(J)*ALPX(6)+V(J)*ALPY(6)+W(J)*ALPZ(6))/TAU(J)      BPT3120
      GO TO (220,230,240), J      BPT3130
      C      B4=K1*(BETX(6)*UTHET(1)+BETY(6)*VTHET(1)+BETZ(6)*WTHET(1))-KBP13210
      220      1      2*(ALPX(6)*UPTH(1)+ALPY(6)*VPTH(1)+ALPZ(6)*WPTH(1))-CPTH(1)BPT3220
      2      K1/C(6)*(U(6)*UPTH(1)+V(6)*VPTH(1)+W(6)*WPTH(1))      BPT3230
      B1=B4/C(6)      BPT3240
      GO TO 250      BPT3250
      C      B4=-K1*(ALPX(6)*UTHET(2)+ALPY(6)*VTHET(2)+ALPZ(6)*WTHET(2))-BPT3260
      230      1      K2*(BETX(6)*UPTH(2)+BETY(6)*VPTH(2)+BETZ(6)*WPTH(2))-CPTH(2)BPT3270
      2      *K1/C(6)*(U(6)*UPTH(2)+V(6)*VPTH(2)+W(6)*WPTH(2))      BPT3280
      B1=B4/C(6)      BPT3290
      GO TO 250      BPT3300
      C      B4=-K1*(BETX(6)*UTHET(3)+BETY(6)*VTHET(3)+BETZ(6)*WTHET(3))-BPT3310
      240      1      K2*(ALPX(6)*UPTH(3)+ALPY(6)*VPTH(3)+ALPZ(6)*WPTH(3))-CPTH(3)BPT3320
      BPT3330
      BPT3340

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2	+K1/C(6)*(U(6)*UPTH(3)+V(6)*VPTH(3)+W(6)*WPTH(3))	BPT3350
	B1=B4/C(6)	BPT3360
C		BPT3370
C	SOLVE SIMULTANEOUSLY FOR ALPHA VARIATION FROM P16 TO BASE POINTS	BPT3380
C		BPT3390
250	ALPTX(J)=(B1*DETM1+B3*DETM2)/DET4	BPT3400
	ALPTY(J)=-(B1*DETM3+B3*DETM4)/DET4	BPT3410
	ALPTZ(J)=(B1*DETM5+B3*DETM6)/DET4	BPT3420
C		BPT3430
C	CALCULATE THE ALPHA AND BETA COMPONENTS FOR ALL J	BPT3440
C		BPT3450
	EALPX=ALPX(6)+ALPTX(J)*TAU(J)	BPT3460
	EALPY=ALPY(6)+ALPTY(J)*TAU(J)	BPT3470
	EALPZ=ALPZ(6)+ALPTZ(J)*TAU(J)	BPT3480
C		BPT3490
C	NORMALIZE ALPHA TO MAKE UNIT VECTOR	BPT3500
C		BPT3510
	NORM=SQRT(EALPX**2+EALPY**2+EALPZ**2)	BPT3520
	ALPX(J)=EALPX/NORM	BPT3530
	ALPY(J)=EALPY/NORM	BPT3540
	ALPZ(J)=EALPZ/NORM	BPT3550
	Q(J)=SQRT(QSQR(J))	BPT3560
	BETX(J)=-(ALPY(J)*W(J)-ALPZ(J)*V(J))/Q(J)	BPT3570
	BETY(J)=-(ALPZ(J)*U(J)-ALPX(J)*W(J))/Q(J)	BPT3580
260	BETZ(J)=-(ALPX(J)*V(J)-ALPY(J)*U(J))/Q(J)	BPT3590
	ASSIGN 50 TO NNN	BPT3600
	PTEST=P(6)	BPT3610
C		BPT3620
C	SOLVE COMPATIBILITY EQUATIONS	BPT3630
C		BPT3640
	CALL BCOMP	BPT3650
	QS=U(6)**2+V(6)**2+W(6)**2	BPT3660
C		BPT3670
C	CONVERGENCE ACCELERATION(REDUCES OVERSHOOT)	BPT3680
C		BPT3690
	P(6)=(P(6)+PTEST)/2.0	BPT3700
	CALL AROSB1 (P(6),PT(5),H(5),A(6),R0(6),QSQR(6))	BPT3710
	C(6)=SQRT(QSQR(6)*A(6)**2/(QSQR(6)-A(6)**2))	BPT3720
	RATIO=SQRT(QSQR(6)/QS)	BPT3730
	U(6)=RATIO*U(6)	BPT3740
	V(6)=RATIO*V(6)	BPT3750
	W(6)=RATIO*W(6)	BPT3760
C		BPT3770
C	TEST TO SEE IF CONVERGED	BPT3780
C		BPT3790
	IF (2.0*ABS(P(6)-PTEST)/PTEST-ERROR) 280,280,270	BPT3800
C		BPT3810
270	CONTINUE	BPT3820
	CALL ERRORS (12)	BPT3830
280	C(6)=SQRT(QSQR(6))	BPT3840
C		BPT3850
C	CALCULATE XSTEP REGULATING PARAMETER	BPT3860
C		BPT3870
	CXDL=U(6)**2/(C(6)*Q(6))*(1.0-C(6)/Q(6)*SQRT(ABS(QSQR(6)/U(6)**2-1.0)))	BPT3880
	Y6=Y(6)	BPT3890
		BPT3900

Z6=Z(6)  
U6=U(6)  
V6=V(6)  
W6=W(6)  
P6=P(6)  
RETURN  
END

BPT3910  
BPT3920  
BPT3930  
BPT3940  
BPT3950  
BPT3960  
BPT3970-



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T125=(TAU(1)+TAU(2))/TAU(1)+TAU(2)-1.0/TAU(5)      BCO 550
B(1)=D1/TAU(1)-D3/TAU(3)-D5*DT31                    BCO 560
B(2)=0.0                                                BCO 570
B(3)=D1/TAU(1)+D2/TAU(2)-D6/TAU(5)-D5*T125          BCO 580
D(1,1)=RCAX6*ST31+(-RO(6)*U(6)-RO(5)*U(5))*DT31+RC1*ALPX(1)/TAU(1) BCO 590
1+RC3*ALPX(3)/TAU(3)                                   BCO 600
C(1,2)=RCAY6*ST31+(-RO(6)*V(6)-RO(5)*V(5))*DT31+RC1*ALPY(1)/TAU(1) BCO 610
1+RC3*ALPY(3)/TAU(3)                                   BCO 620
D(1,3)=RCXZ6*ST31-(RC(6)*W(6)+RO(5)*W(5))*DT31+RC1*ALPZ(1)/TAU(1) BCO 630
1+RC3*ALPZ(3)/TAU(3)                                   BCO 640
C(2,1)=BETX(6)                                          BCO 650
C(2,2)=BETY(6)                                          BCO 660
C(2,3)=BETZ(6)                                          BCO 670
D(3,1)=RCAX6/TAU(1)+RCB6/TAU(2)-(RO(6)*U(6)+RO(5)*U(5))*T125+RC1* BCO 680
1ALPX(1)/TAU(1)+RC2*BETX(2)/TAU(2)                    BCO 690
C(3,2)=RCAY6/TAU(1)+RCB6/TAU(2)-(RO(6)*V(6)+RO(5)*V(5))*T125+RC1* BCO 700
1ALPY(1)/TAU(1)+RC2*BETY(2)/TAU(2)                    BCO 710
C(3,3)=RCXZ6/TAU(1)+RCB6/TAU(2)-(RO(6)*W(6)+RO(5)*W(5))*T125+RC1* BCO 720
1ALPZ(1)/TAU(1)+RC2*BETZ(2)/TAU(2)                    BCO 730
C                                                        BCO 740
C      SOLVE SIMLTANEOUSLY FOR NEW VALUES OF P,U,V,W   T POINT(5) BCO 750
C                                                        BCO 760
CO 90 M=1,4                                             BCO 770
GO TO (10,30,50,70), M                                BCO 780
10 DO 20 J=1,3                                         BCO 790
DO 20 L=1,3                                             BCO 800
20 E(J,L)=D(J,L)                                       BCO 810
GO TO 90                                               BCO 820
C                                                        BCO 830
30 DO 40 J=1,3                                         BCO 840
40 E(J,3)=U(J)                                         BCO 850
GO TO 90                                               BCO 860
C                                                        BCO 870
50 DO 60 J=1,3                                         BCO 880
E(J,3)=D(J,3)                                         BCO 890
60 E(J,2)=B(J)                                         BCO 900
GO TO 90                                               BCO 910
C                                                        BCO 920
70 DO 80 J=1,3                                         BCO 930
E(J,2)=D(J,2)                                         BCO 940
80 E(J,1)=B(J)                                         BCO 950
90 DET(M)=E(1,1)*E(2,2)*E(3,3)-E(3,2)*E(2,3)-E(1,2)*E(2,1)*E(3,3)- BCO 960
1E(3,1)*E(2,3)+E(1,3)*E(2,1)*E(3,2)-E(3,1)*E(2,2) BCO 970
U(6)=DET(4)/DET(1)                                     BCO 980
V(6)=DET(3)/DET(1)                                     BCO 990
W(6)=DET(2)/DET(1)                                     BCO 1000
P(6)=(D5-U(6)*(RO(6)*U(6)+RO(5)*U(5))-V(6)*(RO(6)*V(6)+RO(5)*V(5) BCO 1010
1-W(6)*(RO(6)*W(6)+RO(5)*W(5)))/2.0                  BCO 1020
RETURN                                                  BCO 1030
END                                                    BCO 1040-

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$ORIGIN      C
$IBITC INTER
      SUBROUTINE INTER
C                                                    INR 10
C                                                    INR 20
C      *****
C                                                    INR 30
C                                                    INR 40
C      INTEGRATION OVER INTERIOR POINTS OF SOLUTION SURFACE
C                                                    INR 50
C      *****
C                                                    INR 60
C                                                    INR 70
C                                                    INR 80
C      COMMON /SOLUTN/ Y(2,19,19),Z(2,19,19),U(2,19,19),V(2,19,19),W(2,19,19)
C      1,19),P(2,19,19),PT(19,19),H(19,19),KCLASS(19,19)
C      COMMON /XRGLT/ RM(2,19,19),DXDL(2,19,19),EXCNTR,DELMXN,MMH,NNH,SAFINR
C      ITY
C      COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTY,ICLASS,NP,NT,II,JJ,L,LL
C      IASTART,DELMX,ODELMX,KK,X(2),XMAX,NU
C      I11=NP
C      IF (ICLASS.GT.2) I11=NT-1
C      J1=2
C      JJ1=NP
C      IF (ICLASS.EQ.4) JJ1=NT-1
C      DO 10 I=2,I11
C      IF (ICLASS.EQ.1) J1=1
C      DO 10 J=J1,JJ1
C      II=I
C      JJ=J
C      CALL IPTSU( Y(L,I,J),Z(L,I,J),PT(I,J),H(I,J),Y(LL,I,J),Z(LL,I,
C      1 J),U(LL,I,J),V(LL,I,J),W(LL,I,J),P(LL,I,J),DXDL(LL,I,J))
C      CALL XRGLTR (L,LL,I,J)
C      RETURN
C      END
C                                                    INR 90
C                                                    INR 100
C                                                    INR 110
C                                                    INR 120
C                                                    INR 130
C                                                    INR 140
C                                                    INR 150
C                                                    INR 160
C                                                    INR 170
C                                                    INR 180
C                                                    INR 190
C                                                    INR 200
C                                                    INR 210
C                                                    INR 220
C                                                    INR 230
C                                                    INR 240
C                                                    INR 250
C                                                    INR 260
C                                                    INR 270
C                                                    INR 280
C                                                    INR 290-

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$IBFTC IPTSUB
SUBROUTINE IPTSUB (Y5,Z5,PT5,H5,Y6,Z6,L6,V6,W6,P6,DXDL)      IPT 10
C                                                              IPT 20
C *****                                     IPT 30
C                                     IPT 40
C CALCULATES A NEW INTERIOR POINT OF THE FLOW FRC/ DATA STORED IN THE IPT 50
C THREE DIMENSIONAL ARRAY SU, V, W, P, PT, AND H             IPT 60
C                                     IPT 70
C *****                                     IPT 80
C                                     IPT 90
COMMON /QTSUB/ Y(6),Z(6),U(6),V(6),W(6),P(6),PT(6),H(6),A(6),RO(6) IPT 100
1,C(6),Q(6),QSQR(6),DUDX(6),DUDY(6),DUDZ(6),DVDX(6),VDY(6),DVDZ(6) IPT 110
2,DWDX(6),DWDY(6),DWDZ(6),DPDX(6),DPDY(6),DPDZ(6),DPTDX(6),DPTDY(6) IPT 120
3,DPTDZ(6),DHDX(6),DHDY(6),DHDZ(6),DCDX(6),DCDY(6),DCDZ(6),DADP(6), IPT 130
4,CADH(6),DADPT(6),DRODP(6),DRODPT(6),DRODH(6),ALPX(6),ALPY(6),ALPZ(6) IPT 140
56),BETX(6),BETY(6),BETZ(6),ALPTX(6),ALPTY(6),ALPTZ(6),CPTH(6),UPTH(6) IPT 150
6(6),VPTH(6),WPTH(6),UTHE(6),VTHE(6),WTHE(6),IAU(6),ADBD5      IPT 160
COMMON /CNTRL/ PRINT1,PRINT2,ERROR,IVSTYP,ICLASS,NP,NT,II,JJ,L,LL, IPT 170
1,ASTART,DELX,ODELX,KK,X(2),XMAX,NO
COMMON /INTRP/ B(6,6)
REAL NEUM,K1,K2,NORM,NV,NZ
INTEGER PRNT1,PRNT2
Y(5)=Y5
Z(5)=Z5
CALL INTERP
C
C INTERPOLATE FOR VALUES AT POINT (5)
C
U(5)=B(1,1)+B(2,1)*Y(5)+B(3,1)*Z(5)+B(4,1)*Y(5)*Z(5)+B(5,1)*Y(5)**2 IPT 280
12+B(6,1)*Z(5)**2
V(5)=B(1,2)+B(2,2)*Y(5)+B(3,2)*Z(5)+B(4,2)*Y(5)*Z(5)+B(5,2)*Y(5)**2 IPT 290
12+B(6,2)*Z(5)**2
W(5)=B(1,3)+B(2,3)*Y(5)+B(3,3)*Z(5)+B(4,3)*Y(5)*Z(5)+B(5,3)*Y(5)**2 IPT 300
12+B(6,3)*Z(5)**2
P(5)=B(1,4)+B(2,4)*Y(5)+B(3,4)*Z(5)+B(4,4)*Y(5)*Z(5)+B(5,4)*Y(5)**2 IPT 310
12+B(6,4)*Z(5)**2
PT(5)=PT5
H(5)=H5
C
C CALCULATE PARTIAL DERIVATIVES FOR THE DEPENDENT VARIABLES
C
CUDY(5)=B(2,1)+B(4,1)*Z(5)+2.0*B(5,1)*Y(5)
CUDZ(5)=B(3,1)+B(4,1)*Y(5)+2.0*B(6,1)*Z(5)
CVDY(5)=B(2,2)+B(4,2)*Z(5)+2.0*B(5,2)*Y(5)
DVDZ(5)=B(3,2)+B(4,2)*Y(5)+2.0*B(6,2)*Z(5)
DWDY(5)=B(2,3)+B(4,3)*Z(5)+2.0*B(5,3)*Y(5)
DWDZ(5)=B(3,3)+B(4,3)*Y(5)+2.0*B(6,3)*Z(5)
CPCY(5)=B(2,4)+B(4,4)*Z(5)+2.0*B(5,4)*Y(5)
CPDZ(5)=B(3,4)+B(4,4)*Y(5)+2.0*B(6,4)*Z(5)
C
CALL ARDSJB (P(5),PT(5),H(5),A(5),RG(5),QSQR(5),DADP(5),DADPT(5),D IPT 500
1ADH(5),DRODP(5),DRODPT(5),DRODH(5))
C(5)=SQRT(A(5)**2+QSQR(5)/(QSQR(5)-A(5)**2))
C
CUDX(5)=(RO(5)*U(5)+V(5)*DUDY(5)+W(5)*DUDZ(5))-V(5)*DVDY(5)-W(5)* IPT 540

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1CPDZ(5)=RO(5)*A(5)**2*(DVDY(5)+DWDZ(5))/(RO(5)*(A(5)**2-U(5)**2))IPT 550
C IPT 560
DVDX(5)=(-DPDY(5)-RO(5)*V(5)*DVDY(5)-RO(5)*W(5)*DVDZ(5))/(RO(5)*U(5))IPT 570
15)) IPT 580
C IPT 590
CWDX(5)=(-CPDZ(5)-RO(5)*V(5)*DWDY(5)-RO(5)*W(5)*DWDZ(5))/(RO(5)*U(5))IPT 600
15)) IPT 610
C IPT 620
UUD5=U(5)*(U(5)*DUDX(5)+V(5)*(DVDX(5)+DUDY(5))+W(5)*(DWDX(5)+DUDZ(5))IPT 630
15)))+V(5)*(V(5)*DVDY(5)+W(5)*(DWDY(5)+DVDZ(5)))+W(5)*W(5)*DWDZ(5) IPT 640
ADBD5=DUDX(5)+DVDY(5)+DWDZ(5)-UUD5/QSOR(5) IPT 650
C IPT 660
CPDX(5)=-RO(5)*(U(5)*DJDX(5)+V(5)*DU DY(5)+W(5)*DUDZ(5)) IPT 670
DELY=DELX*V(5)/U(5) IPT 680
DELZ=DELX*W(5)/U(5) IPT 690
P(6)=P(5)+(DPDX(5)*DELX+DPDY(5)*DELY+DPDZ(5)*DELZ)/3.0 IPT 700
C IPT 710
C INITIALIZE LOOP VALUES IPT 720
C IPT 730
IF (P(6)) 10,10,20 IPT 740
10 U(6)=U(5) IPT 750
V(6)=V(5) IPT 760
W(6)=W(5) IPT 770
C(6)=C(5) IPT 780
CSQR(6)=QSOR(5) IPT 790
RU(6)=RO(5) IPT 800
P(6)=P(5) IPT 810
GO TO 30 IPT 820
C IPT 830
20 CALL ARDSB1 (P(6),PT(5),H(5),A(6),RO(6),QSOR(6)) IPT 840
C(6)=SQRT(A(6)**2+QSOR(6)/(QSOR(6)-A(6)**2)) IPT 850
U(6)=U(5)+DUDX(5)*DELX+DUDY(5)*DELY+DUDZ(5)*DELZ IPT 860
V(6)=V(5)+DVDX(5)*DELX+DVDY(5)*DELY+DVDZ(5)*DELZ IPT 870
W(6)=W(5)+DWDX(5)*DELX+DWDY(5)*DELY+DWDZ(5)*DELZ IPT 880
CS=U(6)**2+V(6)**2+W(6)**2 IPT 890
RATIO=SQRT(QSOR(6)/CS) IPT 900
L(6)=RATIO*U(6) IPT 910
V(6)=RATIO*V(6) IPT 920
W(6)=RATIO*W(6) IPT 930
30 ASSIGN 40 TO NIN IPT 940
C IPT 950
C ORIENT NETWORK W.,,T. PRESSURE GRADIENT PROJECTION ON THE Y-Z PLANE IPT 960
C IPT 970
SLOP=DPDZ(5)/DPDY(5) IPT 980
NEUM=SQRT(2.0*(1.0+SLOP**2)) IPT 990
NY=(1.0+SLOP)/NEUM IPT 1000
NZ=(1.0-SLOP)/NEUM IPT 1010
DO 320 N=1,20 IPT 1020
C IPT 1030
C IPT 1040
C FIND COORDINATES OF NEW POINT FOR !TH ITERATION IPT 1050
C IPT 1060
TAU(5)=-2.0*DELX/(U(5)+U(6)) IPT 1070
Y(6)=Y(5)-(V(6)+V(5))*TAU(5)/2.0 IPT 1080
Z(6)=Z(5)-(W(6)+W(5))*TAU(5)/2.0 IPT 1090
C IPT 1100

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C	ESTABLISH SYSTEM OF REFERENCE VECTORS, A AND B	1PT1110
C		1PT1120
C		1PT1130
	NEUM=SQRT((NY*U(6))**2+(NY*W(6)-NZ*V(6))**2+(NZ*U(6))**2)	1PT1140
	ALPX(6)=(NY*W(6)-NZ*V(6))/NEUM	1PT1150
	ALPY(6)=(NZ*U(6))/NEUM	1PT1160
	ALPZ(6)=(-NY*U(6))/NEUM	1PT1170
	DENO=SQRT(QSOR(6))	1PT1180
	BETX(6)=(V(6)*ALPZ(6)-W(6)*ALPY(6))/DENO	1PT1190
	BETY(6)=(W(6)*ALPX(6)-U(6)*ALPZ(6))/DENO	1PT1200
	BETZ(6)=(U(6)*ALPY(6)-V(6)*ALPX(6))/DENO	1PT1210
C		1PT1220
	DET4=BETX(6)*(ALPY(6)*W(6)-V(6)*ALPZ(6))-ALPX(6)*(BETY(6)*W(6)-	1PT1230
1	V(6)*BETZ(6))+U(6)*(BETY(6)*ALPZ(6)-ALPY(6)*BETZ(6))	1PT1240
	DET1=ALPY(6)*W(6)-V(6)*ALPZ(6)	1PT1250
	DET2=BETY(6)*ALPZ(6)-ALPY(6)*BETZ(6)	1PT1260
	DET3=ALPX(6)*W(6)-U(6)*ALPZ(6)	1PT1270
	DET4=BETX(6)*ALPY(6)-ALPX(6)*BETZ(6)	1PT1280
	DET5=ALPX(6)*V(6)-U(6)*ALPY(6)	1PT1290
	DET6=BETX(6)*ALPY(6)-ALPX(6)*BETY(6)	1PT1300
	DO 310 J=1,4	1PT1310
C		1PT1320
	GO TO ANN, (40,50)	1PT1330
C		1PT1340
C	INITIALIZE INNER LOOP	1PT1350
C		1PT1360
40	U(J)=U(5)	1PT1370
	V(J)=V(5)	1PT1380
	W(J)=W(5)	1PT1390
	C(J)=C(5)	1PT1400
	ALPX(J)=ALPX(6)	1PT1410
	ALPY(J)=ALPY(6)	1PT1420
	ALPZ(J)=ALPZ(6)	1PT1430
	BETX(J)=BETX(6)	1PT1440
	BETY(J)=BETY(6)	1PT1450
	BETZ(J)=BETZ(6)	1PT1460
C		1PT1470
C	CALCULATE TAU(J) FOR ITH ITERATION	1PT1480
C		1PT1490
50	GO TO (60,70,80,90), J	1PT1500
C		1PT1510
60	CALPH=C(6)*ALPX(6)+C(1)*ALPX(1)	1PT1520
	GO TO 100	1PT1530
C		1PT1540
70	CALPH=C(6)*BETX(6)+C(2)*BETX(2)	1PT1550
	GO TO 100	1PT1560
C		1PT1570
80	CALPH=-C(6)*ALPX(6)-C(3)*ALPX(3)	1PT1580
	GO TO 100	1PT1590
C		1PT1600
90	CALPH=-C(6)*BETX(6)-C(4)*BETX(4)	1PT1610
100	TAU(J)=2.0*(DELX)/(U(6)+U(J)+CALPH)	1PT1620
C		1PT1630
C	CALCULATE Y(U) FOR THE ITH ITERATION	1PT1640
C		1PT1650
	GO TO (110,120,130,140), J	1PT1660

C			1PT1670
110	CALPY=C(6)*ALPY(6)+C(1)*ALPY(1)		1PT1680
	GO TO 150		1PT1690
C			1PT1700
120	CALPY=C(6)*BETY(6)+C(2)*BETY(2)		1PT1710
	GO TO 150		1PT1720
C			1PT1730
130	CALPY=-C(6)*ALPY(6)-C(3)*ALPY(3)		1PT1740
	GO TO 150		1PT1750
C			1PT1760
140	CALPY=-C(6)*BETY(6)-C(4)*BETY(4)		1PT1770
150	Y(J)=Y(6)+(V(6)+V(J)+CALPY)*TAU(J)/2.0		1PT1780
C			1PT1790
C	CALCULATE Z(J) FOR THE ITH ITERATION		1PT1800
C			1PT1810
	GO TO (160,170,180,190), J		1PT1820
C			1PT1830
160	CALPZ=C(1)*ALPZ(1)+C(6)*ALPZ(6)		1PT1840
	GO TO 200		1PT1850
C			1PT1860
170	CALPZ=C(6)*BETZ(6)+C(2)*BETZ(2)		1PT1870
	GO TO 200		1PT1880
C			1PT1890
180	CALPZ=-C(6)*ALPZ(6)-C(3)*ALPZ(3)		1PT1900
	GO TO 200		1PT1910
C			1PT1920
190	CALPZ=-C(6)*BETZ(6)-C(4)*BETZ(4)		1PT1930
200	Z(J)=Z(6)+(W(6)+W(J)+CALPZ)*TAU(J)/2.0		1PT1940
C			1PT1950
C	CALCULATE VALUES FOR U, V, W, H, P, PT, AND DERIVATIVES AT BASE		1PT1960
C	POINTS		1PT1970
C			1PT1980
	U(J)=B(1,1)+B(2,1)*Y(J)+B(3,1)*Z(J)+B(4,1)*Y(J)*Z(J)+B(5,1)*		1PT1990
1	Y(J)**2+B(6,1)*Z(J)**2		1PT2000
C			1PT2010
	V(J)=B(1,2)+B(2,2)*Y(J)+B(3,2)*Z(J)+B(4,2)*Y(J)*Z(J)+B(5,2)*		1PT2020
1	Y(J)**2+B(6,2)*Z(J)**2		1PT2030
C			1PT2040
	W(J)=B(1,3)+B(2,3)*Y(J)+B(3,3)*Z(J)+B(4,3)*Y(J)*Z(J)+B(5,3)*		1PT2050
1	Y(J)**2+B(6,3)*Z(J)**2		1PT2060
C			1PT2070
	P(J)=B(1,4)+B(2,4)*Y(J)+B(3,4)*Z(J)+B(4,4)*Y(J)*Z(J)+B(5,4)*		1PT2080
1	Y(J)**2+B(6,4)*Z(J)**2		1PT2090
C			1PT2100
	PT(J)=B(1,5)+B(2,5)*Y(J)+B(3,5)*Z(J)+B(4,5)*Y(J)*Z(J)+B(5,5)*		1PT2110
1	Y(J)**2+B(6,5)*Z(J)**2		1PT2120
C			1PT2130
	H(J)=B(1,6)+B(2,6)*Y(J)+B(3,6)*Z(J)+B(4,6)*Y(J)*Z(J)+B(5,6)*		1PT2140
1	Y(J)**2+B(6,6)*Z(J)**2		1PT2150
C			1PT2160
	DUDY(J)=B(2,1)+B(4,1)*Z(J)+2.0*B(5,1)*Y(J)		1PT2170
	CVDY(J)=B(2,2)+B(4,2)*Z(J)+2.0*B(5,2)*Y(J)		1PT2180
	WDY(J)=B(2,3)+B(4,3)*Z(J)+2.0*B(5,3)*Y(J)		1PT2190
	DPDY(J)=B(2,4)+B(4,4)*Z(J)+2.0*B(5,4)*Y(J)		1PT2200
	DPTDY(J)=B(2,5)+B(4,5)*Z(J)+2.0*B(5,5)*Y(J)		1PT2210
	DHDY(J)=B(2,6)+B(4,6)*Z(J)+2.0*B(5,6)*Y(J)		1PT2220

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DUOZ(J)=B(3,1)+B(4,1)*Y(J)+2.0*B(6,1)*Z(J)      IPT2230
DVDZ(J)=B(3,2)+B(4,2)*Y(J)+2.0*B(6,2)*Z(J)      IPT2240
DWDZ(J)=B(3,3)+B(4,3)*Y(J)+2.0*B(6,3)*Z(J)      IPT2250
OPDZ(J)=B(3,4)+B(4,4)*Y(J)+2.0*B(6,4)*Z(J)      IPT2260
DPTDZ(J)=B(3,5)+B(4,5)*Y(J)+2.0*B(6,5)*Z(J)      IPT2270
DHDZ(J)=B(3,6)+B(4,6)*Y(J)+2.0*B(6,6)*Z(J)      IPT2280
C                                                    IPT2290
C   CALCULATE A, RO AND DERIVATIVES AT BASE POINTS      IPT2300
C   FROM THERMODYNAMIC DATA                          IPT2310
C                                                    IPT2320
C   CALL AROSUB (P(J),PT(J),H(J),A(J),RO(J),QSQR(J),DADP(J),DADP      IPT2330
1   T(J),DADH(J),DROUP(J),DRODPT(J),DRODH(J))      IPT2340
C   C(J)=SQRT((A(J)**2)*QSQR(J)/(QSQR(J)-A(J)**2))      IPT2350
C                                                    IPT2360
C   CALCULATE SPACE DERIVATIVES USING ENTROPY AND ENTHALPY CONDITIONS      IPT2370
C   ALONG STREAMLINE                                  IPT2380
C                                                    IPT2390
C   DUDX(J)=(RO(J)*U(J)*V(J)*DUDY(J)+RC(J)*U(J)*W(J)*DUDZ(J)-V(J)      IPT2400
1   )*DPDY(J)-W(J)*DPDZ(J)-RO(J)*A(J)**2*(DVDY(J)+DWDZ(J)))/(RO(J)      IPT2410
2   J)*(A(J)**2-U(J)**2))      IPT2420
C                                                    IPT2430
C   DVDX(J)=(-DPDY(J)-RO(J)*V(J)*DVDY(J)-RC(J)*W(J)*DVDZ(J))/(RO(J)      IPT2440
1   J)*U(J))      IPT2450
C                                                    IPT2460
C   DWDX(J)=(-DPDZ(J)-RO(J)*V(J)*DWDY(J)-RC(J)*W(J)*DWDZ(J))/(RO(J)      IPT2470
1   J)*U(J))      IPT2480
C                                                    IPT2490
C   DDPX(J)=-RO(J)*(U(J)*DDUX(J)+V(J)*DUDY(J)+W(J)*DUDZ(J))      IPT2500
C                                                    IPT2510
C   DHDX(J)=(-V(J)*DHDY(J)-W(J)*DHDZ(J))/U(J)      IPT2520
C                                                    IPT2530
C   DPTDX(J)=(-V(J)*DPTDY(J)-W(J)*DPTDZ(J))/U(J)      IPT2540
C                                                    IPT2550
C   K1=(C(6)**2)/QSQR(6)      IPT2560
C   K2=1.0*K1      IPT2570
C                                                    IPT2580
C   DCDX(J)=C(J)**3*((DADP(J)*DPDX(J)+DADPT(J)*DPTDX(J)+DADH(J)*      IPT2590
1   DHDX(J))/(A(J)**3)-(U(J)*DUDX(J)+V(J)*DVDX(J)+W(J)*DWDX(J))      IPT2600
2   (QSQR(J)**2))      IPT2610
C                                                    IPT2620
C   CCDY(J)=C(J)**3*((DADP(J)*DPDY(J)+DADPT(J)*DPTDY(J)+DADH(J)*      IPT2630
1   DHDY(J))/(A(J)**3)-(U(J)*DUDY(J)+V(J)*DVDY(J)+W(J)*DWDY(J))      IPT2640
2   (QSQR(J)**2))      IPT2650
C                                                    IPT2660
C   DCDZ(J)=C(J)**3*((DADP(J)*DPDZ(J)+DADPT(J)*DPTDZ(J)+DADH(J)*      IPT2670
1   DHDZ(J))/(A(J)**3)-(U(J)*DUDZ(J)+V(J)*DVDZ(J)+W(J)*DWDZ(J))      IPT2680
2   (QSQR(J)**2))      IPT2690
C                                                    IPT2700
C   CALCULATE VARIATION OF ALPHA AND BETA AT BASE POINTS      IPT2710
C                                                    IPT2720
C   GO TO (210,220,230,240), J      IPT2730
C                                                    IPT2740
210 C   CPTH(1)=C(6)*(BETX(6)*DCDX(1)+BETY(6)*CCDY(1)+BETZ(6)*DCDZ(1)      IPT2750
1   )      IPT2760
C   UHT=U(6)+C(6)*ALPX(6)      IPT2770
C   VHT=V(6)+C(6)*ALPY(6)      IPT2780

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C      WYHT=W(6)+C(6)*ALPZ(6)                                IPT2790
C      UPTH(1)=C(6)*(BETX(6)*DUOX(1)+BETY(6)*CLDY(1)+BETZ(6)*DUDZ(1) IPT2800
1      ))                                                       IPT2810
C      VPTH(1)=C(6)*(BETX(6)*DVDX(1)+BETY(6)*CVDY(1)+BETZ(6)*DVDZ(1) IPT2820
1      ))                                                       IPT2830
C      WPTH(1)=C(6)*(BETX(6)*DWDX(1)+BETY(6)*DWDY(1)+BETZ(6)*DWDZ(1) IPT2840
1      ))                                                       IPT2850
C      GO TO 250                                                IPT2860
C      CPTH(2)=C(6)*(-ALPX(6)*DCDX(2)-ALPY(6)*DCDY(2)-ALPZ(6)*DCDZ(2) IPT2870
220 1      ))                                                       IPT2880
C      UTHT=U(6)+C(6)*BETX(6)                                IPT2890
C      VHTT=V(6)+C(6)*BETY(6)                                IPT2900
C      WHTT=W(6)+C(6)*BETZ(6)                                IPT2910
1      UPTH(2)=C(6)*(-ALPX(6)*DUOX(2)-ALPY(6)*DUDY(2)-ALPZ(6)*DUDZ(2) IPT2920
1      ))                                                       IPT2930
C      VPTH(2)=C(6)*(-ALPX(6)*DVDX(2)-ALPY(6)*DVDY(2)-ALPZ(6)*DVDZ(2) IPT2940
1      ))                                                       IPT2950
C      WPTH(2)=C(6)*(-ALPX(6)*DWDX(2)-ALPY(6)*DWDY(2)-ALPZ(6)*DWDZ(2) IPT2960
1      ))                                                       IPT2970
C      GO TO 250                                                IPT2980
C      CPTH(3)=C(6)*(-BETX(6)*DCDX(3)-BETY(6)*DCDY(3)-BETZ(6)*DCDZ(3) IPT2990
230 1      ))                                                       IPT3000
C      UTHT=U(6)-C(6)*ALPX(6)                                IPT3010
C      VHTT=V(6)-C(6)*ALPY(6)                                IPT3020
C      WHTT=W(6)-C(6)*ALPZ(6)                                IPT3030
1      UPTH(3)=C(6)*(-BETX(6)*DUOX(3)-BETY(6)*DUDY(3)-BETZ(6)*DUDZ(3) IPT3040
1      ))                                                       IPT3050
C      VPTH(3)=C(6)*(-BETX(6)*DVDX(3)-BETY(6)*DVDY(3)-BETZ(6)*DVDZ(3) IPT3060
1      ))                                                       IPT3070
C      WPTH(3)=C(6)*(-BETX(6)*DWDX(3)-BETY(6)*DWDY(3)-BETZ(6)*DWDZ(3) IPT3080
1      ))                                                       IPT3090
C      GO TO 250                                                IPT3100
C      CPTH(4)=C(6)*(ALPX(6)*DCDX(4)+ALPY(6)*DCDY(4)+ALPZ(6)*DCDZ(4) IPT3110
240 1      ))                                                       IPT3120
C      UTHT=U(6)-C(6)*BETX(6)                                IPT3130
C      VHTT=V(6)-C(6)*BETY(6)                                IPT3140
C      WHTT=W(6)-C(6)*BETZ(6)                                IPT3150
1      UPTH(4)=C(6)*(ALPX(6)*DUOX(4)+ALPY(6)*DUDY(4)+ALPZ(6)*DUDZ(4) IPT3160
1      ))                                                       IPT3170
C      VPTH(4)=C(6)*(ALPX(6)*DVDX(4)+ALPY(6)*DVDY(4)+ALPZ(6)*DVDZ(4) IPT3180
1      ))                                                       IPT3190
C      WPTH(4)=C(6)*(ALPX(6)*DWDX(4)+ALPY(6)*DWDY(4)+ALPZ(6)*DWDZ(4) IPT3200
1      ))                                                       IPT3210
C      UTHET(J)=UTHT*DUOX(J)+VHTT*DUDY(J)+WHTT*DUDZ(J)      IPT3220
250 VTHET(J)=UTHT*DVDX(J)+VHTT*DUDY(J)+WHTT*DUDZ(J)        IPT3230
C      WTHET(J)=UTHT*DWDX(J)+VHTT*DWDY(J)+WHTT*DWDZ(J)      IPT3240
C      B3=-(U(J)*ALPX(6)+V(J)*ALPY(6)+W(J)*ALPZ(6))/TAU(J)  IPT3250

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C          GO TO (260,270,280,290), J          IPT3350
C          IPT3360
260      B4=K1*(BETX(6)*UTHE(1)+BETY(6)*VTHE(1)+BETZ(6)*WTHE(1))-K1PT3370
1          2*(ALPX(6)*UPTH(1)+ALPY(6)*VPTH(1)+ALPZ(6)*WPTH(1))-CPH(1)+IPT3380
2          K1/C(6)*(U(6)*UPTH(1)+V(6)*VPTH(1)+W(6)*WPTH(1))          IPT3390
          B1=B4/C(6)          IPT3400
          GO TO 300          IPT3410
C          IPT3420
270      B4=-K1*(ALPX(6)*UTHE(2)+ALPY(6)*VTHE(2)+ALPZ(6)*WTHE(2))-IPT3430
1          K2*(BETX(6)*UPTH(2)+BETY(6)*VPTH(2)+BETZ(6)*WPTH(2))-CPH(2)+IPT3440
2          +K1/C(6)*(U(6)*UPTH(2)+V(6)*VPTH(2)+W(6)*WPTH(2))          IPT3450
          B1=B4/C(6)          IPT3460
          GO TO 300          IPT3470
C          IPT3480
280      B4=-K1*(BETX(6)*UTHE(3)+BETY(6)*VTHE(3)+BETZ(6)*WTHE(3))+IPT3490
1          K2*(ALPX(6)*UPTH(3)+ALPY(6)*VPTH(3)+ALPZ(6)*WPTH(3))-CPH(3)+IPT3500
2          +K1/C(6)*(U(6)*UPTH(3)+V(6)*VPTH(3)+W(6)*WPTH(3))          IPT3510
          B1=B4/C(6)          IPT3520
          GO TO 300          IPT3530
C          IPT3540
290      B4=K1*(ALPX(6)*UTHE(4)+ALPY(6)*VTHE(4)+ALPZ(6)*WTHE(4))+K1PT3550
1          2*(BETX(6)*UPTH(4)+BETY(6)*VPTH(4)+BETZ(6)*WPTH(4))-CPH(4)+IPT3560
2          K1/C(6)*(U(6)*UPTH(4)+V(6)*VPTH(4)+W(6)*WPTH(4))          IPT3570
          B1=B4/C(6)          IPT3580
C          IPT3590
C          SOLVE SIMULTANEOUSLY FOR ALPHA VARIATION FROM PT(6) TO BASE POINTS IPT3600
C          IPT3610
300      ALPTX(J)=(B1*DETM1+B3*DETM2)/DET4          IPT3620
          ALPTY(J)=-(B1*DETM3+B3*DETM4)/DET4          IPT3630
          ALPTZ(J)=(B1*DETM5+B3*DETM6)/DET4          IPT3640
C          IPT3650
C          CALCULATE THE ALPHA AND BETA COMPONENTS FOR ALL J          IPT3660
C          IPT3670
          EALPX=ALPX(6)+ALPTX(J)*TAU(J)          IPT3680
          EALPY=ALPY(6)+ALPTY(J)*TAU(J)          IPT3690
          EALPZ=ALPZ(6)+ALPTZ(J)*TAU(J)          IPT3700
C          IPT3710
C          NORMALIZE ALPHA TO MAKE UNIT VECTOR          IPT3720
C          IPT3730
          NORM=SQRT(EALPX**2+EALPY**2+EALPZ**2)          IPT3740
          ALPX(J)=EALPX/NORM          IPT3750
          ALPY(J)=EALPY/NORM          IPT3760
          ALPZ(J)=EALPZ/NORM          IPT3770
          Q(J)=SQRT(QSOR(J))          IPT3780
          BETX(J)=-(ALPY(J)*W(J)-ALPZ(J)*V(J))/Q(J)          IPT3790
          BETY(J)=-(ALPZ(J)*U(J)-ALPX(J)*W(J))/Q(J)          IPT3800
310      BETZ(J)=-(ALPX(J)*V(J)-ALPY(J)*U(J))/Q(J)          IPT3810
          ASSIGN 50 TO NNN          IPT3820
          PTEST=P(6)          IPT3830
C          IPT3840
C          SOLVE COMPATIBILITY EQUATIONS          IPT3850
C          IPT3860
          CALL COMPAT          IPT3870
          QS=U(6)**2+V(6)**2+W(6)**2          IPT3880
          P(6)=(P(6)+PTEST)/2.0          IPT3890
C          IPT3900

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	CALL AROSBI (P(6),PT(5),H(5),A(6),RQ(6),QSQR(6))	PT3910
	C(6)=SQRT(QSQR(6)*A(6)**2/(QSQR(6)-A(6)**2))	PT3920
	RATIO=SQRT(QSQR(6)/Q5)	PT3930
	U(6)=RATIO*U(6)	PT3940
	V(6)=RATIO*V(6)	PT3950
	W(6)=RATIO*W(6)	PT3960
	IF (2.0*ABS(P(6)-PTEST)/PTEST-ERROR) 330,370,320	PT3970
320	CONTINUE	PT3980
	CALL ERRORS (11)	PT3990
330	C(6)=SQRT(QSQR(6))	PT4000
C		PT4010
C	CALCULATE XSTEP REGULATING PARAMETER	PT4020
C		PT4030
	DXDL=U(6)**2/(C(6)*Q(6))*(1.0-C(6)/Q(6))*SQRT(ABS(QSQR(6)/U(6)**2-1.0))	PT4040
	Y6=Y(6)	PT4050
	Z6=Z(6)	PT4060
	U6=U(6)	PT4070
	V6=V(6)	PT4080
	W6=W(6)	PT4090
	P6=P(6)	PT4100
	RETURN	PT4110
	END	PT4120
		PT4130-

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SIBFTC COMPAT
SUBROUTINE COMPAT
C
C *****
C
C SOLVES THE INTERIOR POINT COMPATIBILITY EQUATIONS
C
C *****
C
C DIMENSION E(3,3), D(3,3), B(3), BET(4)
COMMON /QTSUB/ Y(6),Z(6),U(6),V(6),W(6),P(6),PT(6),H(6),A(6),RC(6),M
1,C(6),Q(6),QSQR(6),DUDX(6),DUDY(6),DUDZ(6),DVDX(6),DVDY(6),DVDZ(6),CUM
2,DWDX(6),DWDY(6),DWDZ(6),DPDX(6),DPOY(6),DPDZ(6),DPTDX(6),DPTDY(6),CUM
3,DPTDZ(6),DMUX(6),DMDY(6),DMDZ(6),DCDX(6),DCDY(6),DCDZ(6),DADP(6),CUM
4,DADH(6),DAOPT(6),DRODP(6),DROOPT(6),DRODH(6),ALPX(6),ALPY(6),ALPZ(CUM
56),BETX(6),BETY(6),BETZ(6),ALPTX(6),ALPTY(6),ALPTZ(6),CPTH(6),UPTH(CUM
6(4),VPTH(4),WPTH(4),LTHET(4),VTHET(4),WTHET(4),TAU(6),ADBD5
C
C CALCULATE COEFFICIENTS FOR SIMULTANEOUS DIFFERENCE EQUATIONS FOR UCM
C
C BBD1=E 1)*(BETX(1)*DUDX(1)+BETY(1)*(DVDX(1)+DUDY(1))+BETZ(1)*(DCUM
1WDX(1)+DUDZ(1))+BETY(1)*(BETY(1)*DVDY(1)+BETZ(1)*(DWDY(1)+DVDZ(1)CUM
2)))+BETZ 1)*BETZ(1)*DWDZ(1)
C
C BBD3=BETX(3)*(BETX(3)*DUDX(3)+BETY(3)*(DVDX(3)+DUDY(3))+BETZ(3)*(DCUM
1WDX(3)+DUDZ(3))+BETY(3)*(BETY(3)*DVDY(3)+BETZ(3)*(DWDY(3)+DVDZ(3)CUM
2)))+BETZ(3)*BETZ(3)*DWDZ(3)
C
C AAD2=ALPX(2)*(ALPX(2)*DUDX(2)+ALPY(2)*(DVDX(2)+DUDY(2))+ALPZ(2)*(DCUM
1WDX(2)+DUDZ(2))+ALPY(2)*(ALPY(2)*DVDY(2)+ALPZ(2)*(DWDY(2)+DVDZ(2)CUM
2)))+ALPZ(2)*ALPZ(2)*DWDZ(2)
C
C AAD4=ALPX(4)*(ALPX(4)*DUDX(4)+ALPY(4)*(DVDX(4)+DUDY(4))+ALPZ(4)*(DCUM
1WDX(4)+DUDZ(4))+ALPY(4)*(ALPY(4)*DVDY(4)+ALPZ(4)*(DWDY(4)+DVDZ(4)CUM
2)))+ALPZ(4)*ALPZ(4)*DWDZ(4)
C
C
C RC6=RU(6)*C(6)
C RC1=RO(1)*C(1)
C RC2=RO(2)*C(2)
C RC3=RO(3)*C(3)
C RC4=RO(4)*C(4)
C RC5=RO(5)*C(5)
C RCAX6=RC6*ALPX(6)
C RCAY6=RC6*ALPY(6)
C RCZ6=RC6*ALPZ(6)
C RCBX6=RC6*BETX(6)
C RCBY6=RC6*BETY(6)
C RCBZ6=RC6*BETZ(6)
C D1=2.0*P(1)+(RCAX6+RC1*ALPX(1))*U(1)+(RCAY6+RC1*ALPY(1))*V(1)+(RCACUM
1Z6+RC1*ALPZ(1))*W(1)+RC1*RC(1)*BBD1*TAU(1)
C D2=2.0*P(2)+(RCBX6+RC2*BETX(2))*U(2)+(RCBY6+RC2*BETY(2))*V(2)+(RCACUM
1Z6+RC2*BETZ(2))*W(2)+RC2*RC(2)*AAD2*TAU(2)
C D3=2.0*P(3)-(RCAX6+RC3*ALPX(3))*U(3)-(RCAY6+RC3*ALPY(3))*V(3)-(RCACUM
1Z6+RC3*ALPZ(3))*W(3)+RC3*RC(3)*GBD3*TAU(3)
C
CUM 10
CUM 20
CUM 30
CUM 40
CUM 50
CUM 60
CUM 70
CUM 80
CUM 90
CUM 100
CUM 110
CUM 120
CUM 130
CUM 140
CUM 150
CUM 160
CUM 170
CUM 180
CUM 190
CUM 200
CUM 210
CUM 220
CUM 230
CUM 240
CUM 250
CUM 260
CUM 270
CUM 280
CUM 290
CUM 300
CUM 310
CUM 320
CUM 330
CUM 340
CUM 350
CUM 360
CUM 370
CUM 380
CUM 390
CUM 400
CUM 410
CUM 420
CUM 430
CUM 440
CUM 450
CUM 460
CUM 470
CUM 480
CUM 490
CUM 500
CUM 510
CUM 520
CUM 530
CUM 540

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D4=2.0*P(4)-(RCBX6*RC4*HITX(4)+U(4)-(RCBY6*RC4*UFTY(4))*V(4)-(RCHC6*H 550
176*RC4*HITZ(4))*W(4)+RL4+C(4)*AAU4*TAU(4) CUM 560
TS=2.0*P(5)+(RU(6)*U(6)+RO(5)*U(5))*U(5)+(RU(6)*V(6)+RO(5)*V(5))*VCUM 570
1(5)+(RU(6)*W(6)+RO(5)*W(5))*W(5) CUP 580
U6=2.0*P(5)+RC5*C(5)*ADHDS+TAU(5) CUP 590
SF3=(TAU(1)+TAU(3))/TAU(1)/TAU(3) CUP 600
ST4=(TAU(4)+TAU(2))/TAU(4)/TAU(2) CUP 610
CT3=(TAU(3)-TAU(1))/TAU(3)/TAU(1) CUP 620
CT4=(TAU(4)-TAU(2))/TAU(4)/TAU(2) CUM 630
T125=(TAU(1)+TAU(2))/TAU(1)/TAU(2)-1.0/TAU(5) CUP 640
B(1)=D1/TAU(1)-D3/TAU(3)-D5*DT31 CUP 650
E(2)=D2/TAU(2)-D4/TAU(4)-D5*DT42 CUP 660
B(3)=D1/TAU(1)+D2/TAU(2)-D6/TAU(5)-D5*T125 CUM 670
C(1,1)=RCAX6*SF3+(-RU(6)*U(6)-RU(5)*U(5))*DT31+RC1*ALPX(1)/TAU(1) CUM 680
1+RC3*ALPX(3)/TAU(3) CUP 690
C(1,2)=RCAY6*ST4+(-RU(6)*V(6)-RU(5)*V(5))*DT21+RC1*ALPY(1)/TAU(1) CUM 700
1+RC3*ALPY(3)/TAU(3) CUM 710
C(1,3)=(-RO(6)*W(6)-RU(5)*W(5))*DT31+RC1*ALPZ(1)/TAU(1)+RC3*ALPZ(3) CUM 720
1/TAU(3)+RCZ6*SF3 CUP 730
C(2,1)=RCBX6*ST2+(-RU(6)*U(6)-RU(5)*U(5))*DT42+RC2*BTX(2)/TAU(2) CUP 740
1+RC4*BTX(4)/TAU(4) CUM 750
C(2,2)=RCBY6*ST4+(-RU(6)*V(6)-RU(5)*V(5))*DT42+RC2*BTY(2)/TAU(2) CUM 760
1+RC4*BTY(4)/TAU(4) CUP 770
C(2,3)=RCZ6*ST4+(-RU(6)*W(6)-RU(5)*W(5))*DT42+RC2*BTZ(2)/TAU(2) CUP 780
1+RC4*BTZ(4)/TAU(4) CUM 790
C(3,1)=RCAX6/TAU(1)+RCBX6/TAU(2)-(-RU(6)*U(6)+RO(5)*U(5))*T125+RC1 CUM 800
1ALPX(1)/TAU(1)+RC2*BTX(2)/TAU(2) CUP 810
F(3,2)=RCAY6/TAU(1)+RCBY6/TAU(2)-(-RU(6)*V(6)+RO(5)*V(5))*T125+RC1 CUM 820
1ALPY(1)/TAU(1)+RC2*BTY(2)/TAU(2) CUM 830
C(3,3)=RCZ6/TAU(2)-(-RU(6)*W(6)+RO(5)*W(5))*T125+RC1 CUM 840
1ALPZ(1)/TAU(1)+RC2*BTZ(2)/TAU(2)+RCZ6/TAU(3) CUP 850
CUM 860
C SOLVE SIMULTANEOUSLY FOR NEW VALUES OF P,U,V,W AT POINT(6) CUM 870
C CUM 880
C CUM 890
C CUM 900
10 DO 20 J=1,3 CUM 910
    DO 20 L=1,3 CUM 920
20 E(J,L)=U(J,L) CUP 930
    GO TO 90 CUM 940
C CUM 950
30 DO 40 J=1,3 CUP 960
40 E(J,3)=B(J) CUP 970
    GO TO 90 CUM 980
C CUM 990
50 DO 60 J=1,3 CUM 1000
    E(J,3)=B(J,3) CUM 1010
60 L(J,2)=B(J) CUM 1020
    GO TO 90 CUM 1030
C CUM 1040
70 DO 80 J=1,3 CUM 1050
    L(J,2)=U(J,2) CUM 1060
80 E(J,1)=B(J) CUM 1070
90 L(1,1)=E(1,1)+E(1,2)+E(1,3)+E(2,1)+E(2,2)+E(2,3)+E(3,1)+E(3,2)+E(3,3) CUM 1080
    L(6)=D(1,4)/D(1,1) CUM 1090

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V(6)=DET(3)/DET(1)	COM1110
W(6)=DET(2)/DET(1)	COM1120
P(6)=(D5-U(6)*(RO(6)*U(6)+RO(5)*U(5))-V(6)*(RO(6)*V(6)+RO(5)*V(5))	COM1130
1-W(6)*(RO(6)*W(6)+RO(5)*W(5)))/2.0	COM1140
RETURN	COM1150
END	COM1160-

10	ORIGIN	C	
	10	IBFIC PRNOUT	
		SUBROUTINE PRNOUT	PRN 10
C			PRN 20
C		*****	PRN 30
C			PRN 40
C		PRINT OUT SOLUTION SURFACE(ESSENTIALLY THE SAME AS PRN1VS)	PRN 50
C			PRN 60
C		*****	PRN 70
C			PRN 80
		COMMON /SOLUTM/ Y(2,19,19),Z(2,19,19),L(2,19,19),V(2,19,19),W(2,19,19),P(2,19,19),PT(19,19),H(19,19),K(19,19)	PRN 90
		COMMON /CHTKL/ PRINT1,PRINT2,ERROR,ISTYP,ICLASS,NP,NT,II,JJ,L,LL	PRN 100
		INSTART,DELX,DELX,KK,X(2),KMAX,NO	PRN 110
		COMMON /XGGLT/ RM(2,19,19),DXDL(2,19,19),EXCNR,DELXMH,PPM,NAH,SAP	PRN 120
		ITY	PRN 130
		COMMON /CONST/ PI,DRAD,BTU,G,BTUOG	PRN 140
		COMMON /THRU1/ AREA,AREAT,FMASS,XTHR1,YTHR1,ZTHR1,XTHR,YTHR,ZTHR,XPM	PRN 150
		YPM,ZPM,PM,PM,FMASS1,RMASS	PRN 160
		INTEGER PRINT1,PRINT2	PRN 170
		NO=NP	PRN 180
		IF (ICLASS.GT.2) NO=NT	PRN 190
		NPRINT=PRINT1+1	PRN 200
		LINE=11	PRN 210
10		GO TO (10,40,80), NPRINT	PRN 220
		WRITE (6,110) X(LL),KK	PRN 230
		WRITE (6,150) AREAT,RMASS,XTHR,YTHR,ZTHR,XMONT,YMONT,ZMONT	PRN 240
		WRITE (6,160)	PRN 250
		WRITE (6,120)	PRN 260
		WRITE (6,130)	PRN 270
		J2=NP	PRN 280
		IF (ICLASS.EQ.4) J2=NO	PRN 290
		DO 30 I=1,NO,PRINT2	PRN 300
		J1=1	PRN 310
		IF (ICLASS.EQ.1) J1=1	PRN 320
		DO 30 J=J1,J2,PRINT2	PRN 330
		IF (LINE.LE.54) GO TO 20	PRN 340
		WRITE (6,110) X(LL),KK	PRN 350
		WRITE (6,120)	PRN 360
		WRITE (6,130)	PRN 370
		LINE=1	PRN 380
20		LINE=LINE+1	PRN 390
		TOLP=PT(1,J)/144.C	PRN 400
		TOLH=H(1,J)/BTUOG	PRN 410
		WRITE (6,140) I,J,Y(LL,I,J),Z(LL,I,J),W(LL,I,J),V(LL,I,J),P(LL,I,J),PT(I,J),H(I,J),K(I,J)	PRN 420
1		),V(LL,I,J),P(LL,I,J),U(LL,I,J),V(LL,I,J),L(LL,I,J),TOLP,TOLH	PRN 430
30		CONTINUE	PRN 440
		GO TO 100	PRN 450
C			PRN 460
40		WRITE (6,110) X(LL),KK	PRN 470
		WRITE (6,150) AREAT,RMASS,XTHR,YTHR,ZTHR,XMONT,YMONT,ZMONT	PRN 480
		WRITE (6,170)	PRN 490
		WRITE (6,120)	PRN 500
		WRITE (6,130)	PRN 510
		J2=NP	PRN 520
			PRN 530

IF (ICLASS.EQ.4) J7=NO	PRN 540
DO 70 I=1,NO,PRINT2	PRN 550
J1=1	PRN 560
IF (ICLASS.EQ.1) J1=1	PRN 570
DO 70 J=J1,J2,PRINT2	PRN 580
IF (I.EQ.1.OR.J.EQ.1) GO TO 50	PRN 590
IF (I.EQ.NO.OR.J.EQ.NO) GO TO 50	PRN 600
GO TO 70	PRN 610
C	PRN 620
50 IF (LINE.LE.54) GO TO 60	PRN 630
WRITE (6,110) X(ILL),KK	PRN 640
WRITE (6,120)	PRN 650
WRITE (6,130)	PRN 660
LINE=1	PRN 670
60 TOLP=PT(I,J)/144.C	PRN 680
LINE=LINE+1	PRN 690
TOLM=H(I,J)/8TDOG	PRN 700
1 WRITE (6,140) I,J,Y(LL,I,J),Z(LL,I,J),W(L,I,J),Z(L,I,J),Y(L,I,J),JPRN 710	
I,V(L,I,J),P(L,I,J),U(LL,I,J),V(LL,I,J),W(LL,I,J),TOLP,TOLM	PRN 720
70 CONTINUE	PRN 730
GO TO 100	PRN 740
C	PRN 750
80 IF (LINE.LT.55) GO TO 90	PRN 760
LINE=0	PRN 770
WRITE (6,190)	PRN 780
90 WRITE (6,180) X(ILL),KK	PRN 790
LINE=LINE+11	PRN 800
WRITE (6,150) ARFAT,RMASS,XTHR,YTHR,ZTHR,XMOMT,YMOMT,ZMOMT	PRN 810
100 WRITE (6,200) MPM,MNN,SAFTY,DELTA	PRN 820
RETURN	PRN 830
C	PRN 840
C	PRN 850
110 FORMAT (1H1,18HSOLUTION SURFACE -,10X,3HX =,2X,F8.4,2X,4H(IN),4X,6PRN 860	
IMPLANE ,12)	PRN 870
120 FORMAT (1H0,10X,1H1,2X,1HJ,6X,1HY,8X,1HZ,8X,1HW,8X,1HG,9X,1HP,7X,3PRN 880	
1HRHO,9X,1HT,9X,1HU,10X,1HV,8X,1HW,7X,2HPT,8X,1HH)	PRN 890
130 FORMAT (1H ,18X,4H(IN),5X,4H(IN),12X,8H(FT/SEC),1X,9H(LBF/IN2),2X,PRN 900	
19H(LBM/FT3),2X,7H(DEG X),3X,8H(FT/SEC),2X,8H(FT/SEC),1X,8H(FT/SEC),4X 910	
2,9H(LBF/IN2),1X,9H(BTU/LBM/))	PRN 920
140 FORMAT (1H ,9X,12,1X,12,2X,F7.4,2X,F7.4,2X,F7.3,2X,F7.1,2X,F8.2,2XPRN 930	
1,E10.4,2X,F7.1,2X,F8.1,2X,F8.1,2X,F7.1,2X,F7.1,2X,F8.1)	PRN 940
150 FORMAT(1H0,10X,106HTHRUST PARAMETERS (THRUST COMPONENTS HAVE BEEN PRN 950	
1MULTIPLIED BY THE RATIO OF INITIAL TO LOCAL PASS FLOW RATE)/1H ,1PRN 960	
2CX,18MCROSS SECTION AREA-,2X,F10.4,2X,7H(IN**2),4X,22HMASS FLOW RAPHN 970	
3TE RATIO =,2X,F10.5,1H ,10X,9HXTHRUST =,2X,F9.2,1X,5H(LBF),6X,9HPRN 980	
4YTHRUST =,2X,F7.2,1X,5H(LBF),6X,9HXTHRUST =,2X,F7.2,1X,5H(LBF),7PRN 990	
5H ,10X,9HXMOMT =,2X,F9.2,1X,8H(FT-LBF),3X,9HXMOMT =,2X,F7.2,1XPRN 1000	
6,8H(FT-LBF),3X,9HXMOMT =,2X,F7.2,1X,8H(FT-LBF))	PRN 1010
160 FORMAT (1H0,10X,37HBOUNDARY AND INTERIOR FLOW PARAMETERS)	PRN 1020
170 FORMAT (1H0,10X,24HBOUNDARY FLOW PARAMETERS)	PRN 1030
180 FORMAT (1H0,18HSOLUTION SURFACE -,10X,3HX =,2X,F8.3,2X,4H(IN),4X,PRN 1040	
16HPLANE ,21)	PRN 1050
190 FORMAT (1H1)	PRN 1060
200 FORMAT (1H0,10X,27HSTEP REGULATION PARAMETERS//1H ,10X,19H1PRN 1070	
16 POINT 1 =,1X,12,5H AND,1X,3HJ = ,12,5X,16HSAFETY FACTOR = ,FPRN 1080	
210.5,5X,10HDELTA X = ,F10.4)	PRN 1090
END	PRN 1100

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## DOCUMENT CONTROL DATA - R &amp; D

Purdue University Lafayette, Ind. 47907		UNCLASSIFIED
A SECOND-ORDER NUMERICAL METHOD OF CHARACTERISTICS FOR THREE-DIMENSIONAL SUPERSONIC FLOW, VOLUME II, COMPUTER PROGRAM USER'S MANUAL		
Technical Report covering the period 1 September 1966 to 31 December 1969		
V. H. Ransom, M. C. Cline, J. D. Hoffman, and H. D. Thompson		
January 1970	10 TOTAL NO OF PAGES 217	11 0
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14 SPONSORING MILITARY AGENCY Air Force Aero Propulsion Laboratory Wright-Patterson Air Force Base, Ohio		
<p>A new method of characteristics numerical scheme for three-dimensional steady flow has been developed which has second-order accuracy. Heretofore all such schemes for three-dimensional flow have had accuracies less than second-order. A complete numerical algorithm for computing internal supersonic flows of the type encountered in ramjet, scramjet or rocket propulsion systems has been developed and programmed for both the IBM 7094 and CDC 6500 computers. The method has been tested for order of accuracy using the exact solution for source flow and Prandtl-Meyer flow. The results of these tests have verified the second-order accuracy of the scheme. Additional accuracy tests using existing methods for solution of two-dimensional axisymmetric flows have shown that the scheme produces accuracies comparable to that of the two-dimensional method of characteristics. The computer program has been used to generate the flow field for several three-dimensional nozzle contours and for nonsymmetric flow into an axisymmetric nozzle. These results reveal the complex nature of three-dimensional flows and the general inadequacy of quasi-three-dimensional analyses which neglect crossflow. An operationally convenient computer program was produced. The program has the capability to analyze nonisoenergetic and nonhomentropic flows of a calorically perfect gas or homentropic flows of a real gas in chemical equilibrium. The initial-value surface options include uniform flow, source flow or axisymmetric tabular data. The nozzle boundary options include conical nozzles, axisymmetric contoured nozzles and super-elliptical nozzles.</p>		

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KEY WORDS	LINK A		LINK B		LINK C	
	MOLE	WT	ROLE	WT	MOLE	WT
Scramjet Technology Exhaust Nozzles Method of Characteristics Three-Dimensional Flow						

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